Water Quality Management Report No. 91-2

Effects of The Town of The Pas Sewage Lagoon Discharges on The Water Quality of Grace Lake

By A.E. Beck.

Manitoba
Environment

EFFECTS OF THE TOWN OF THE PAS SEWAGE LAGOON DISCHARGES ON THE WATER QUALITY OF GRACE LAKE

A Report to the Grace Lake Water Quality Management Board

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SUMMARY

The Minister of Environment directed that a water quality study of Grace Lake be undertaken and that a Water Quality Management Board be established for the Lake. This was in response to public concerns regarding deteriorating water quality conditions in Grace Lake. Many local people attributed the deteriorating water quality in Grace Lake to Town of The Pas sewage lagoon discharges which had been directed to Grace Lake since 1973.

A Water Quality Management Board for Grace Lake, consisting of 12 members representing local interests and related government departments, was established on April 10, 1990. Terms of Reference adopted by the Board included examination of the effects from sewage lagoon discharges, determination of the extent of potential recovery upon cessation of sewage discharge, examination of the implications of various sewage disposal options, examination of effects upon the local aquifer, review of criteria for lake level management and dyke maintenance, examination of the implications of increased resource use and review of land use zoning. The present report discusses the results of the water quality study from the perspective of the first four Terms of Reference cited. The report also presents a record of the minutes of Board meetings.

The water quality study of Grace Lake was based on a comparison to a nearby lake (Montreal Lake) with an undisturbed, natural watershed and on correlation of the concentrations of various parameters to distance from the mouth of the lagoon effluent stream. The study determined that depressed dissolved oxygen levels and elevated concentrations of organically bound nitrogen, ammonia nitrogen, total phosphorus, total dissolved phosphorus and sulphate were directly attributable to discharges from the sewage lagoon. The proliferation of aquatic weeds and the greatly increased degree of algal production which is stimulated by the presence of excessive quantities of nutrients, were indirectly attributable to discharges from the sewage lagoon. Elevated concentrations of other parameters such as sodium were linked to infiltration by groundwater. Although coliform bacteria levels in Grace Lake appeared to be superficially linked to lagoon discharges, the levels were well within guidelines considered acceptable for body contact recreational activities such as swimming. However, aesthetic qualities such as excessive weed and algae growth and turbidity would impair such recreational activities.

The potential for recovery of Grace Lake water quality was assessed through development of phosphorus budgets. The budget developed for current conditions in the lake revealed that recycling of nutrients was the dominant factor presently stimulating algae and weed growth. Hydraulic loadings from lagoon discharges were estimated to be equivalent to the present outflow from Grace Lake. Therefore, Grace Lake water quality probably would not change if

lagoon discharges to the lake were halted because there would be insufficient natural inflows to flush the lake. However, the water quality would improve marginally (10% - 13%) if lagoon effluents were to receive a phosphorus removal treatment. Under these conditions, the maximum improvement in water quality was estimated to occur in approximately 12.5 years.

Notwithstanding the preceding results, various options for disposal of sewage lagoon effluent were identified and reviewed. These included 3 options involving continued discharge to Grace Lake and 5 options involving discharge elsewhere. The no modification, lake treatment, deep well injection, farmland irrigation and discharge to Montreal Lake options were rejected as being unacceptable, not feasible or comparatively too expensive. Options deemed worthy of further evaluation included treatment of lagoon effluents and discharge to either the Saskatchewan River or Cemetary Lake. Given the potential for at least some minor improvement in Grace Lake water quality, it was recommended that the lagoon effluent treatment option be given preference. The Saskatchewan River and Cemetary Lake options were not preferred because of their potential to cause environmental impact elsewhere without causing an improvement in Grace Lake.

Concerns about possible contamination of local wells by infiltration from Grace Lake were examined by correlating well water chemistry to distance from Grace Lake. Chemical evidence of aquifer recharge due to infiltration from Grace Lake was not detected. Rather, Grace Lake hydraulic loading estimations incorporated in the phosphorus budgets indicated that local groundwater was actually discharging to Grace Lake. Therefore, the water quality of Grace Lake had no effect on local wells.

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II Composition of the Grace Lake Water Quality Management Board

III Terms of Reference for the Grace Lake Water Quality Management Board

IV Minutes of Meetings of the Grace Lake Water Quality Management Board

- (i) April 10, 1990
- (ii) June 19, 1990
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- (ia) Grace Lake, April 11, 1990
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VI Chemistry of Well Water from the Grace Lake Area.

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1.0 INTRODUCTION

A Clean Environment Commission (CEC) Hearing in January 1970 reviewed the Town of The Pas application for construction and operation of a sewage lagoon. CEC Order #330 was issued on December 13, 1973 and has since regulated operation of the lagoon and the quality of its wastewater discharge to Grace Lake. Limits of the Order (Appendix I) have been met since issuance (D. Peterson* pers. comm.).

Persons dwelling within the L.G.D. of Consol and near to Grace Lake have repeatedly complained since the mid 1970s of odours, seepage from the dykes encompassing Grace Lake and deteriorating water quality within the lake. There is a history of requests for studies and resolution of the problem. Most recently (January 9, 1990), the L.G.D. of Consol requested that the Honourable J. Glen Cummings, Minister of Environment, undertake a study of the problem and identify remedial solutions.

The L.G.D. of Consol was advised by ministerial letter dated January 31, 1990 that the CEC would be asked to review the operation of the Town of The Pas lagoon and to evaluate the operational limits imposed by Order #330. Departmental staff were requested to undertake a water quality study of Grace Lake and to establish a Water Quality Management Board for the Lake. The Board was to be comprised of representatives of local interests and appropriate officials from various government departments.

The L.G.D. of Consol, the Town of The Pas, Grace Lake float plane

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* D. Peterson, P. Eng., Chief of Environmental Approvals, Manitoba Department of Environment.

operators and a group entitled "Friends of Grace Lake" were invited to send representatives to an initial organizational meeting on April 10, 1990. The attendance of officials from Water Resources Branch, Lands Branch, Wildlife Branch and Manitoba Environment was also requested. Both Board organization and adoption of Terms of Reference were achieved during the initial meeting (Appendices II and III, respectively). Minutes of Board meetings are presented in Appendix IV.

The purpose of this report is to present and discuss the results of the Grace Lake water quality study undertaken by Manitoba Environment. Specific objectives of the study included:

a) to examine the impact of Town of The Pas sewage lagoon discharges upon the water quality of Grace Lake;

b) to determine the extent to which the water quality of Grace Lake would recover if sewage discharge were discontinued;

c) to identify and examine the implications of various sewage disposal options; and,

d) to determine whether aquifer recharge from Grace Lake is contaminating local wells.

Issues pertaining to other Terms of Reference such as implications of increased resource use, lake level management criteria and land use zoning are not discussed. These topics are addressed in other reports to the Board.

2.0 DESCRIPTION OF STUDY AREA

Grace Lake (53°50, 101°10) is located 3 kilometres east of The Pas in northwestern Manitoba (Figure 1). It is broadly triangular in shape with its apex oriented in a northerly direction. Maximum dimensions are approximately 4.5 X 3.5 kilometres. It is accessible by float plane or by Provincial Road #285 via Highway #10.

Montreal Lake (53°47, 101°07) is located approximately 3 kilometres southeast of Grace Lake. It is narrow, triangular in shape, with its apex oriented in a westerly direction. Maximum dimensions are approximately 3.5 X 1.25 kilometres. It is not accessible by road.

2.1 Physiographic Setting

The study area is underlain by dolomite of Silurian age (Davies et al, 1962). Test hole drilling near the western perimeter of the study area indicates that the bedrock is overlain by 43 to 57 metres of varied layers of clay and till (Underwood McLellan and Associates Limited, 1972). This in turn is overlain by a thin mantle of poorly drained brunisols along western reaches of the study area, which merge easterly with a slightly thicker layer of organic soils (Weir, 1983). Peat is well developed in low lying areas. The topography is virtually level.

Natural vegetation over much of the area is dense climax black spruce forest. Some aspen and balsam poplar occur on the heights of land separating the Grace Lake and Montreal Lake watersheds. Birch and aspen also occur on the few well drained portions of lake shoreline. Open marshes dominated by cattail and reeds (both Phragmites sp. and Scirpus spp.) occur north of Grace Lake and east of Montreal Lake. Willows are also abundant.

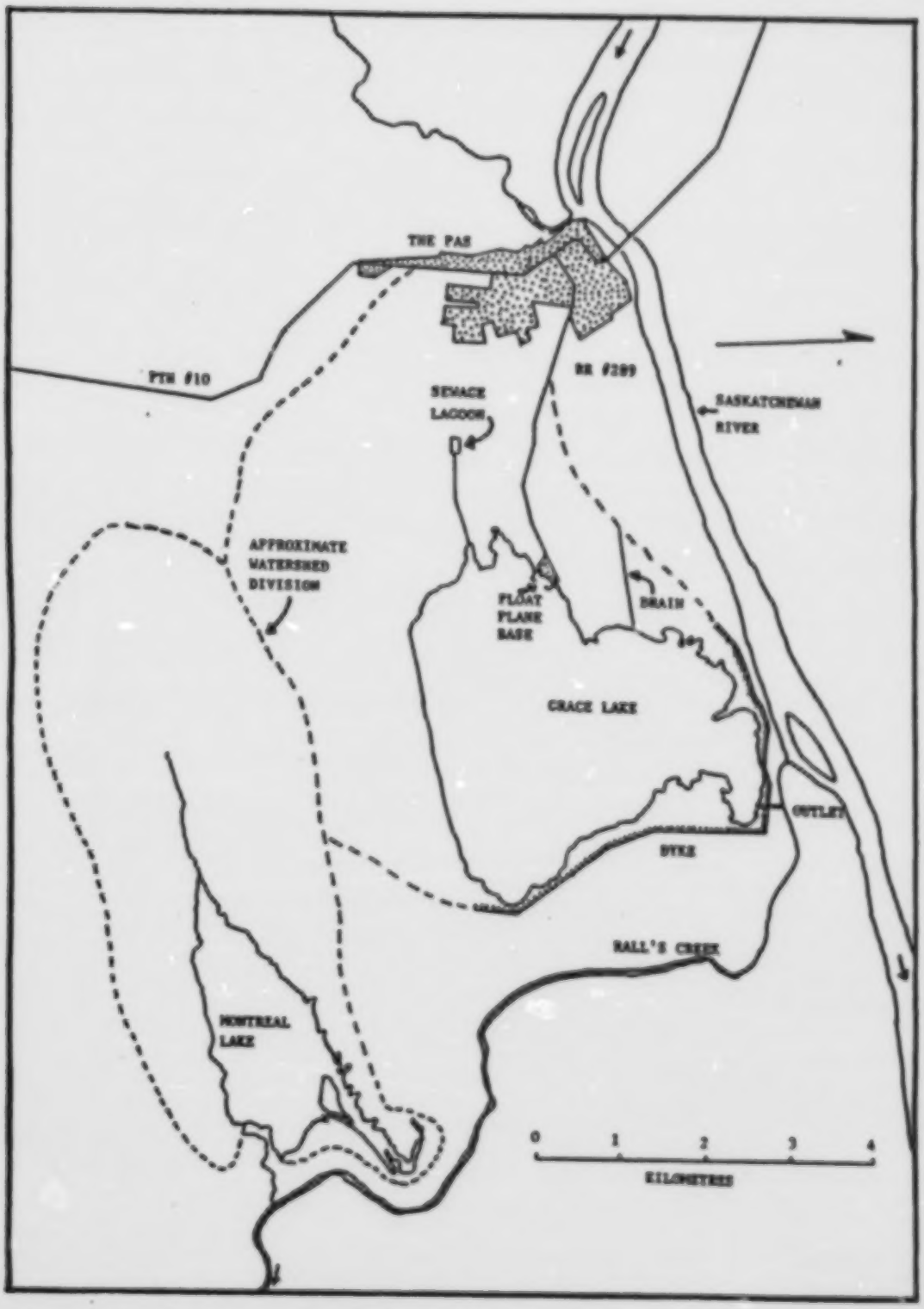

FIGURE 1: The Grace Lake study area.

2.2 Climate

The climate of The Pas is continental. Mean annual precipitation is approximately 450 millimetres, about 2/3 of which falls as rain (Weir, 1983). The January mean daily temperature is -21.1°C (Ibid). The June mean daily temperature is 17.8°C (Ibid). The mean frost free period is approximately 100 days (Ibid). Winds are predominantly from the north-westerly and south-easterly directions.

2.3 Drainage Area and Hydrology

2.3.1 Grace Lake

Grace Lake has a surface area of approximately 10.6 Km^2 (Water Resources, 1990). Its natural gross drainage area of 28.5 Km^2 (Ibid) has been increased to about 31.6 Km^2 by connection to the Town of The Pas sewage lagoon (Figure 1). The lagoon receives storm water from a portion of the Town.

Grace Lake is shallow with a mean depth of approximately 1.68 metres and a maximum depth of 2.10 metres. The total volume of water in the lake is estimated at 1.78×10^7 cubic metres.

There are no natural streams flowing into or from Grace Lake. Natural runoff and seepage from the drainage basin over the long-term is virtually equivalent to evaporation from the lake surface. However, historically during wet years, flows from Grace Lake proceeded easterly in an undefined manner towards Rall's Creek.

Two artificial drains discharge to Grace Lake. The first drains a small bog area north of the Grace Lake airfield. The second conducts continuous discharges from the Town of The Pas sewage lagoon. The lagoon discharge rate varies from approximately 3,640 to 4,550 cubic metres per day, dependent primarily upon the operation of "bleeder" lines during winter (N. Fulford*, pers. comm.) Lagoon discharges generate most of the flows exiting Grace Lake. Assuming a mean discharge rate of 4,095 cubic metres per day, lagoon discharges over the course of one year (i.e., 1,494,675 cubic metres) are equivalent to 0.14 metres of water when spread over the entire surface area of Grace Lake.

The present outlet from Grace Lake consists of a gated 1.83 m diameter culvert which discharges into a short drain leading to Rail's Creek (Water Resources, 1990). A flow meter has not been installed on the discharge from Grace Lake. However, discharges may be assumed to be equivalent to loadings from the sewage lagoon since losses to evaporation and seepage likely would not be significantly elevated over natural background.

2.3.2 Montreal Lake

Montreal Lake, the study control, has a surface area of approximately 3.05 Km^2. Its natural gross drainage area is estimated at 21.3 Km^2 (Figure 1). It is a shallow lake with a mean depth of approximately 1.86 metres and a maximum depth of 2.4 metres. The total volume of water in the lake is estimated at 5.67×10^6 cubic metres.

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* N. Fulford, Municipal Superintendent, Town of The Pas.

A single natural stream enters Montreal Lake from its westerly apex. Although the stream retains water virtually year round, flows are intermittent due to the small size of the bog area drained. Flows from the lake exit from a marshy area at the southeast end of the lake. These flows have not been metered.

2.4 Water Level Management*

The Grace Lake dyke was constructed in 1957 by the Water Resources Branch in order to allow higher levels to be maintained for float plane operation. The dyke is approximately one metre high and extends for a total length of 6.4 kilometres along the north and east sides of the lake. It was constructed of a mixture of peat and some clay, the natural material present along the edge of the lake during construction.

Initially, formal rules for regulating the level of Grace Lake were not developed. However, the occurrence of seepage problems which affected residences north of the west dyke resulted in the formulation and adoption of operating rules during late 1986. Under these rules, the lake is lowered to the winter target level (260.25 metres above sea level) in mid October. During summer months, efforts are made to prevent levels from exceeding the summer target level of 260.50 metres A.S.L. This is sufficient to minimize seepage through the dyke. The minimum level required for safe operation of float planes is 260.25 metres A.S.L. The minimum elevation of the top of the dyke is approximately at 260.97 metres A.S.L.

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* Abstracted from Water Resources, 1990

The original outlet control structure was replaced in 1983. The present structure consists of a gated 1.83 metre diameter conduit with an approximate invert elevation of 259.10 metres A.S.L. Icing problems in the drain downstream of the outlet prevent effective winter releases from the lake. Therefore, lake levels increase over the winter months due to influxes of lagoon effluent.

Maintenance work on the external drain adjacent to the Grace Lake dyke was carried out in the fall of 1989. This involved brush clearing and drain excavation. Most of the excavated material was placed on the lake side of the dyke. This maintenance work improved the efficiency of the external drain and reduced the risk of flooding from local runoff and seepage.

Montreal Lake water levels are maintained naturally.

2.5 Local Development and Uses

Developments and uses of Grace Lake are listed in Table 1. The order of listing, roughly according to chronology and intensity of use, is not intended to convey priority.

Trapping is the only known use of Montreal Lake apart from natural usage by waterfowl and wildlife.

TABLE 1: DEVELOPMENTS AND USES OF GRACE LAKE

Use	Comments
Float Plane Base	- Currently, it is used by Beaver Air Services Limited and several private owners of float planes. - Formerly, it was used extensively as a base for fire management activities by Department of Natural Resources.
Residential	- Approximately 35 - 37 residences are located immediately north of the dyke.
Grace Lake Airfield	- The proximity of an airfield to a float plane base provides an opportunity for repair and changeover (wheels to floats) facilities.
Warehousing	- The Department of Natural Resources maintains an equipment depot and laboratory facilities.
Sewage effluent	- The Town of The Pas has been licensed to discharge sewage lagoon effluents to Grace Lake since 1973.
Trapping	- Muskrat and some beaver are harvested. The total value of production was estimated at $3000 in 1986.
Waterfowl	- Extensive use of the lake is made by mudhen, mallards, blue-wing teal, widgeon and others.
Wild Rice	- Although production has not occurred in recent years, one Licence is held on the lake. Occasionally, wild rice seed is stored in the lake overwinter.
Dog Kennel	- Several sled dog owners maintain kennels west of the float plane base.
Cattle Watering	- At least one cattle operator waters cattle from Grace Lake periodically during the summer.
Waterfowl Hunting	- Some hunting occurs along the dyke.
Bird Sanctuary/ Interpretive Centre	- Several persons have proposed that Grace Lake be managed as a bird sanctuary.
Recreation	- Several persons have expressed a desire for enhanced recreational opportunities such as canoeing, swimming and nature observation.

3.0 PROCEDURES

Studies which assess environmental impacts arising from developments rely on comparisons between appropriate sets of data. Ideally, one set of data is taken from the period before development occurred and a second set of data is accumulated after the development has become operational. An alternate approach, particularly useful in the absence of predevelopment data, involves comparisons to a surrogate, i.e., data from a site that closely resembles the site under study except for the absence of the development in question. Such a surrogate is known as a study "control."

The virtual absence of quantitative water chemistry data from the period before sewage effluents were routed to Grace Lake necessitated use of a study control. Montreal Lake was selected as a control, primarily because of its proximity to Grace Lake (thereby implying similar influence from climate and geology), and because the watershed remains in a natural, virtually undisturbed state. Similarly sized and adjacent drainage basins and approximately equivalent mean depths were also significant factors.

3.1 Effects of Sewage

The purpose of this aspect of the study was to examine the impact of Town of The Pas sewage lagoon discharges upon the water quality of Grace Lake. Since sewage lagoon effluents were the primary source* of non-natural

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* Other factors which might affect Grace Lake water quality include spillage from aircraft refuelling and runoff from sites such as the airfield and the Natural Resources Warehousing area. However, parameters likely to be influenced by such factors (eg., petroleum, metals) were excluded from the study.

hydraulic loadings to Grace Lake, a simple comparison of mean water chemistry to that of the study control (Montreal Lake) was deemed adequate to identify and quantify negatively influenced parameters. Supportive evidence was to be drawn from correlation to distance from the mouth of the sewage lagoon effluent discharge stream. Variations between seasons were also to be investigated because biological processes are greatly influenced by seasonal factors such as temperature, sunlight and ice cover.

A total of ten and five sampling stations were established on Grace and Montreal lakes, respectively (Figure 2). Stations were distributed along the linear axis of Grace Lake in order that distances from the mouth of the effluent stream to the various sampling stations could be readily calibrated. Sampling sites were also distributed linearly on Montreal Lake for the sake of study consistency. Distance calibration during winter sampling expeditions was achieved by using a four-wheeled all terrain vehicle equipped with an odometer. Location of sampling sites during ice free sampling expeditions was approximated by triangulation.

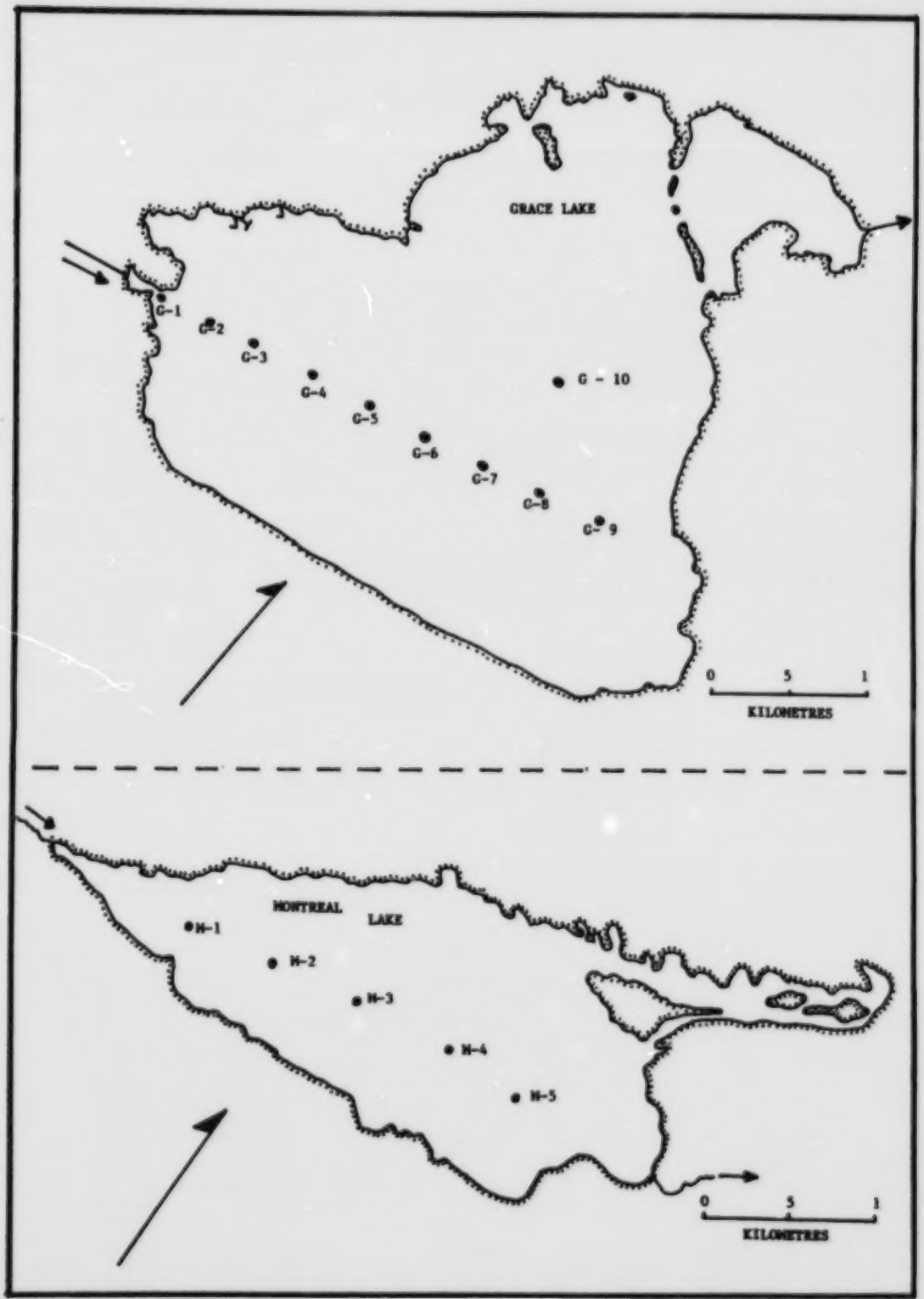

FIGURE 2: Water chemistry sampling stations on Grace and Montreal Lakes.

A total of five sampling expeditions were conducted. Dates of the expeditions were April 11, June 19, July 31, September 6 and November 28, 1990.

Water samples were collected using a 2.2 L pesticide grade acrylic Kemmerer sampler. Sampling depths were determined by considering random numbers a percentage of total depth at each station. Transparency was measured by Secchi disc and recorded. Depth integrated chlorophyll "a" samples were collected at a maximum of twice the Secchi depth by using an integrated sampler.

All samples were shipped "on ice" by scheduled bus service to the W.M. Ward Technical Services Laboratory so as to arrive within 24 hours of collection. Analyses were performed at the laboratory according to procedures described by Sorba et al (1980).

3.2 Lake Recovery

The most obvious symptoms of poor water quality in Grace Lake are the massive algae blooms and the abundant growths of aquatic weeds (macrophytes). Growth of these plants is stimulated by an abundant nutrient supply. The process, whereby an excessive nutrient supply triggers massive algae blooms and macrophyte populations, is termed "eutrophication." Typically, phosphorus is the key nutrient which causes eutrophication.

The purpose of this aspect of the study was to determine the extent to which the water quality of Grace Lake would recover if sewage discharges were discontinued.

The approach adopted in the present study was to develop a current phosphorus budget for Grace Lake using the procedures outlined by Hough, Stansbury and Michalski Limited (1980) as adapted by Beck (1988). Subsequent calculations were completed to evaluate various scenarios such as the elimination of hydraulic and phosphorus loadings from sewage effluent discharges and reduced rates of phosphorus loadings. These calculations were calibrated with current water quality data from Grace and Montreal lakes, respectively. Predicted phosphorus concentrations in turn were used to estimate chlorophyll concentrations. Chlorophyll is a measure of algal abundance (Carlson, 1977) and may be used as an indicator of the state of eutrophy.

Lake flushing rates for the various scenarios were an integral calculation of the predicted spring phosphorus concentration (i.e., step 10 of Table 5). Lake recovery was inferred as being equivalent to total replacement of the lake water through one complete flushing of the lake.

3.3 Disposal Options

The purpose of this aspect of the study was to identify the various sewage disposal options available and to examine the environmental implications of each of these options. Possible options were identified by a review of Manitoba Environment files pertaining to wastewater disposal methods adopted by various communities and industries across Manitoba. Other

techniques were acquired through discussion with Saskatchewan Environment and Public Safety and with Alberta Environment. General environmental implications of the various options were drawn from the literature. Where possible, inferences were drawn by using available data to quantify impacts.

3.4 Aquifer Contamination

The purpose of this aspect of the study was to determine whether aquifer recharge from Grace Lake was contaminating local wells. Concerns relevant to this issue include the rate of aquifer recharge, direction of groundwater flow and speed of groundwater flows. These types of questions are best addressed by detailed piezometer studies which continue for several years. A detailed piezometer study was beyond the fiscal capabilities and temporal constraints of the present study.

The alternative approach, adopted in the present study, was first to determine whether local wells were contaminated and then to determine whether correlations existed between well distances from Grace Lake and various chemical parameters in respective wells' water. Well water data for these purposes were extracted from local Inspection Services (Manitoba Environment) files. Data drawn from treated supplies (e.g., iron removal, water softening) were excluded from documentation and analysis. Additionally, regional hydrogeology reports were reviewed.

4.0 RESULTS AND DISCUSSION

Water chemistry data for Grace and Montreal Lakes is detailed in Appendix V. Appendix VI describes the chemistry of well water samples from the study area.

4.1 Effects of Sewage

Summaries of water chemistry analytical results for Grace and Montreal Lakes are presented in Table 2. Results of statistical comparisons ($t\alpha = 0.05$) between chemistries of the two lakes are presented in Table 3. Results are discussed in terms of individual parameters as ordered in Table 2.

Conductivity, or specific conductance, is a measure of the ability of water to conduct an electrical current. Because this ability is proportional to the presence of dissolved minerals, conductivity provides a general indication of water purity. The mean conductivity for Grace Lake (694 umho/cm) was significantly greater (Table 3) than that of Montreal Lake (251 umho/cm). However, Grace Lake conductivity was not significantly correlated ($r = 0.185$; Table 4) to distance from the mouth of the sewage effluent stream. This suggested that although a significantly greater amount of minerals were dissolved in the water of Grace Lake, most of the dissolved minerals could not be directly linked to discharges from the sewage lagoon. It is more likely that the comparatively elevated conductivity of Grace Lake was a function of the lake's small drainage basin and its lack of a natural outlet. During most years, Grace Lake would have had little opportunity to flush itself of dissolved minerals that might have accumulated due to evaporation.*

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* Estimates of natural basin outflows derived from Table 5 suggest that the natural lake level was maintained by groundwater inflows since surficial inflows were insufficient to compensate for the evaporation deficient.

TABLE 2: SUMMARY OF WATER CHEMISTRY DATA FOR GRACE LAKE AND MONTREAL LAKE

Parameter	GRACE LAKE Mean	Maximum	Minimum	Standard Deviation	MONTREAL LAKE Mean	Maximum	Maximum	Standard Deviation
Conductivity (umho/cm)	694	1250	359	180	251	308	176	33
pH (units)	8.49	9.47	7.20	-	8.29	9.24	7.17	-
Alkalinity ($CaCO^3$ mg/L)	273	498	116	68.8	129	156	82.9	16.2
Alkalinity (HCO^3 mg/L)	285	608	142	113.8	139	190	74.9	35.3
Alkalinity (CO^3 mg/L)	22.3	69.3	0	25.4	9.1	35.8	0	11.6
Alkalinity (OH mg/L)	0	0	0	0	0	0	0	0
Calcium mg/L	43.7	74.0	16.1	10.5	26.3	33.5	18.9	3.3
Magnesium (mg/L)	38.8	62.8	20.0	8.4	18.3	22.2	11.8	2.5
Hardness (mg $CaCO^3$/L)	269	443	123	57.9	141.2	173	96.5	17.6
Sodium (mg/L)	47.0	73.5	24.0	10.0	3.87	5.00	3.19	0.60
Potassium (mg/L)	7.4	11.9	5.0	1.6	5.0	5.0	5.0	0
Iron (mg/L)	0.57	1.46	0.01	0.44	0.58	3.9	0.01	0.92
Manganese (mg/L)	0.18	1.14	0.02	0.27	0.11	0.49	0.015	0.11
Dissolved Oxygen (mg/L)	6.6	11.5	0.1	3.20	8.7	12.2	1.3	2.27
Colour (TCU)	38	G50	10	13	26	50	10	8
Turbidity (NTU)	8.0	29	0.5	9.0	3.69	7.8	1.15	1.80
Total Kjeldhal Nitrogen (mg/L)	5.07	28.40	1.50	4.33	1.30	2.95	0.95	0.41
Ammonia Nitrogen (mg/L)	2.508	24.40	0.026	4.103	0.050	0.330	0.006	0.070
Dissolved Nitrogen (mg/L)	0.12	0.74	0.01	0.13	0.03	0.14	0.01	0.03
Total Phosphorus (mg/L)	0.959	4.75	0.335	0.794	0.064	0.28	0.026	0.06
Total Dissolved Phosphorus (mg/L)	0.748	4.33	0.090	0.780	0.019	0.14	0.009	0.024
Chloride (mg/L)	55	98	25	12.8	0.95	1.65	1.65	0.28
Sulphate (mg/L)	29	78	15	16.38	4.6	25	0.65	6.19
Silicon Dioxide (mg/L)	13.4	37.9	5.4	6.88	3.8	7.0	1.0	-
Fecal Coliform (No./100 ml)	56.3	1100	0	242	0.7	4	0	2
Chlorophyll 'a' (ug/L)	43.2	108	1	33.42	13.6	23.6	4.0	6.46

TABLE 3: COMPARISON ($t\alpha = 0.05$) OF GRACE LAKE AND MONTREAL LAKE WATER CHEMISTRY

Parameter	"t" Value	Comments
Conductivity	13.634	Grace Lake values are significantly greater.
pH	0.860	No significant difference.
Alkalinity (CaC03)	11.923	Grace Lake values are significantly greater.
Alkalinity (HC03)	6.181	Grace Lake values are significantly greater.
Alkalinity (C03)	3.176	Grace Lake values are significantly greater.
Alkalinity (OH)	0	No significant difference.
Calcium	7.951	Grace Lake values are significantly greater.
Magnesium	11.912	Grace Lake values are significantly greater.
Hardness	10.703	Grace Lake values are significantly greater.
Sodium	27.968	Grace Lake values are significantly greater.
Potassium	10.607	Grace Lake values are significantly greater.
Iron	0.039	No significant difference.
Manganese	1.136	No significant difference.
Dissolved Oxygen	2.242	Montreal Lake values are significantly greate
Colour	3.386	Grace Lake values are significantly greater.
Turbidity	4.135	Grace Lake values are significantly greater.
Total Kjeldhal Nitrogen	5.388	Grace Lake values are significantly greater.
Ammonia Nitrogen	4.130	Grace Lake values are significantly greater.
Dissolved Nitrogen	3.632	Grace Lake values are significantly greater.
Total Phosphorus	7.156	Grace Lake values are significantly greater.
Total Dissolved Phosphorus	6.316	Grace Lake values are significantly greater.
Chloride	28.905	Grace Lake values are significantly greater.
Sulphate	6.710	Grace Lake values are significantly greater.
Silicon Dioxide	6.860	Grace Lake values are significantly greater.
Fecal Coliform	1.605	No significant difference.
Chlorophyll - 'a'*	3.716	Grace Lake values are significantly greater.

* Summer values only.

TABLE 4: Correlations (t_α = 0.05) OF CRACK LAKE WATER CHEMISTRY PARAMETERS TO DISTANCE (m) FROM THE MOUTH OF THE LAGOON EFFLUENT STREAM

Parameter	Correlation Coefficient	Statistical Significance	Slope Direction	Level of Significance
Conductivity	0.185	No	-	-
pH	0.206	No	-	-
Alkalinity ($CaCO_3$)	0.095	No	-	-
Alkalinity (HCO_3)	0.127	No	-	-
Alkalinity (CO_3)	0.079	No	-	-
Alkalinity (OH)	-	-	-	-
Calcium	0.258	No	-	-
Magnesium	0.129	No	-	-
Hardness	0.108	No	-	-
Sodium	0.187	No	-	-
Potassium	0.189	No	-	-
Iron	0.019	No	-	-
Manganese	0.035	No	-	-
Dissolved Oxygen	0.288	Yes	Positive	96.4%
Colour	0.312	Yes	Negative	97.3%
Turbidity	0.078	No	-	-
Kjeldhal Nitrogen	0.406	Yes	Negative	99.7%
Ammonia Nitrogen	0.441	Yes	Negative	99.9%
Dissolved Nitrogen	0.013	No	-	-
Total Phosphorus	0.524	Yes	Negative	99.9%
Total Dissolved Phosphorus	0.533	Yes	Negative	99.9%
Chloride	0.166	No	-	-
Sulphate	0.400	Yes	Negative	99.6%
Silicon Dioxide	0.075	No	-	-
Fecal Coliform	0.320	Yes	Negative	95.6%
Chlorophyll - 'a'	0.201	No	-	-

The relative acidity of water is indicated by the pH scale, where 7.0 represents neutrality and values above and below 7.0 are respectively indicative of alkaline and acidic conditions. Typically, small waterbodies subject to sewage loadings are characterized by extensive algae blooms; respiration from algae blooms can sometimes significantly raise pH values in certain types of lakes. Mean pH values for Grace Lake and Montreal Lake were 8.49 and 8.29 units, respectively. There was no significant difference ($t_{\alpha} = 0.05$) between the mean pH values (Table 3). This suggested that sewage lagoon effluent discharges had not affected Grace Lake pH values either directly of indirectly.

Both calcium carbonate and bicarbonate alkalinities provide a measure of cation availability within water; hence, a measure of the water's ability to buffer or neutralise acidic inputs. Both measures of alkalinity were significantly greater ($t_{\alpha} = 0.05$) in Grace Lake than in Montreal Lake (Table 3). However, correlations on distance from the mouth of the sewage effluent stream were not significant ($r = 0.093$ and 0.127, respectively; Table 4). This suggested that the significant difference might not be linked to discharges of sewage lagoon effluent. Rather, given the calcium carbonate and bicarbonate alkalinities in local wellwater (Appendix VI) and a hydrological balance suggestive of significant input of groundwater to Grace

Lake (Table 5), it can be inferred that the comparatively elevated alkalinities of Grace Lake were attributable to inflows of groundwater. However, there is insufficient evidence for a conclusive statement in this regard.

Carbonate alkalinity provides a crude measure of algae respiration. High carbonate alkalinities are indicative of algae blooms. Mean carbonate alkalinities for Grace and Montreal Lakes (22.3 and 9.1 mg/L, respectively) indicate that substantial algae blooms occur on both lakes. However, a significant difference (t_α = 0.05) between the two means (Table 3) suggests that algae productivity is much more extensive on Grace Lake.

Hydroxyl alkalinity, which can be indicative of certain industrial loadings, was not detected in either lake (Table 2).

Calcium is of significance in surface waters because it provides an indication of buffering capacity, the ability to neutralize acidic inputs. Mean calcium concentrations of Grace Lake (43.7 mg/L) were significantly greater (t_α = 0.05; Table 3) than those of Montreal Lake (26.3 mg/L). As with the calcium carbonate and bicarbonate alkalinities, correlations on distance from the mouth of the sewage lagoon effluent stream were not significant (r = 0.258; Table 4). This means that the comparatively elevated calcium levels might not be linked to discharges of sewage lagoon effluent. Concentrations in local wellwater (Appendix VI) suggest that groundwater discharges to Grace Lake might also be a source of calcium.

Like calcium, magnesium is also indicative of buffering capacity. Results (Tables 3 and 4) are similar to those of calcium and may be interpreted in a similar fashion.

Hardness may be defined as water's capacity to precipitate soap, primarily by action of calcium, magnesium and iron ions. Expressed as calcium carbonate equivalency, hardness provides a measure of the total cation activity. Considering the results for calcium and magnesium, it was not surprising that the mean hardness of Grace Lake (269 mg/L, Table 2) was significantly greater ($t\alpha = 0.05$, Table 3) than that of Montreal Lake (141 mg/L, Table 2).

Sodium, present in domestic wastes, can sometimes be used to trace the path of sewage effluents in low ion, soft water aquatic systems. Mean sodium concentrations in Grace Lake (47.0 mg/L, Table 2) were significantly greater ($t\alpha = 0.05$; Table 3) than in Montreal Lake (3.87 mg/L, Table 2). However, there was no positive correlation to distance from the mouth of the lagoon effluent stream ($r = 0.069$, Table 4). Complicating factors such as concentration of salts by evaporation and probable infiltration of groundwater with comparatively elevated sodium concentrations (Appendix VI), rendered sodium inoperable as a tracer of the sewage effluent path through Grace Lake.

Potassium is a nutrient essential for the growth of living organisms. Like sodium, it is also present in domestic wastes and may sometimes be used to trace the path of sewage effluent through aquatic systems. Mean potassium concentrations in Grace Lake (7.4 mg/L) were significantly greater ($t\alpha = 0.05$, Table 3) than those in Montreal Lake

(5.0 mg/L). As with sodium, the absence of a significant correlation ($r = 0.189$; Table 4) to distance from the mouth of the sewage effluent stream implied that there was no link between potassium levels and sewage discharges. A link to groundwater infiltration was considered; however, supportive evidence was not available as well water samples had not been analyzed for potassium content.

Iron and manganese provide important evidence of the chemical dynamics which occur at the water sediment interface. Elevated levels indicate that bottom waters are devoid of oxygen and that anaerobic activities are liberating phosphorus from the sediments (Barica, 1977). Such releases of phosphorus stimulate algae growth and can perpetuate hyper-eutrophic conditions even in the absence of external phosphorus loading. The anoxic conditions in turn, are attributable to the large organic content of the lake sediments.

Mean iron and manganese concentrations in Grace Lake were 0.57 mg/L and 0.18 mg/L, respectively (Table 2). These were not significantly different ($t^{\alpha} = 0.05$, Table 3) than the values encountered in Montreal Lake (0.58 mg/L and 0.11 mg/L, respectively; Table 2). High iron and manganese values (i.e., ≥ 0.10 mg/L and ≥ 0.05 mg/L, respectively) were observed in nearly all samples (Appendix V). This indicated that reducing conditions favourable to the release of phosphorus from sediments were present at the bottom of both lakes on a nearly continuous basis.

Adequate levels of dissolved oxygen (i.e., > 47% saturation) are critical for the well being of aquatic organisms such as fish (Williamson, 1986) Even relatively short periods of inadequate dissolved oxygen levels can result in the elimination of fish and other sensitive aquatic organisms from a lake. During the study period, dissolved oxygen levels in Grace Lake were adequate during all but the April 1990 sampling period. This was sufficient to eliminate fish and other organisms dependent upon moderate levels of dissolved oxygen. Serious oxygen depletion was not observed across Montreal Lake during any sampling period.

Mean dissolved oxygen concentrations in Montreal Lake (8.7 mg/L, Table 2) were significantly greater ($t_{\alpha} = 0.05$, Table 3) than in Grace Lake (6.6 mg/L). Grace Lake dissolved oxygen concentrations were significantly correlated ($r = 0.336$, Table 4) to distance from the mouth of the sewage lagoon effluent stream (Figure 3). This suggested that the oxygen demand of organic loadings from the sewage lagoon effluent exceeded the assimilative capacity of Grace Lake, especially during periods of ice cover.

Colour in natural waters is imparted by materials such as tannic and humic acids which originate from decomposing vegetation. Grace Lake waters were coloured (mean = 38 true colour units) to a significantly greater degree ($t_{\alpha} = 0.05$, Table 3) than that of Montreal Lake, although the latter was also highly coloured (mean = 26 true colour units). The colour of Grace Lake water was significantly correlated ($r = 0.312$, Table 4) to distance from the mouth of the sewage lagoon stream. Although this implied that the source of the colour differential was associated with discharges from the sewage lagoon, the correlation was considered to be spurious due to the overriding

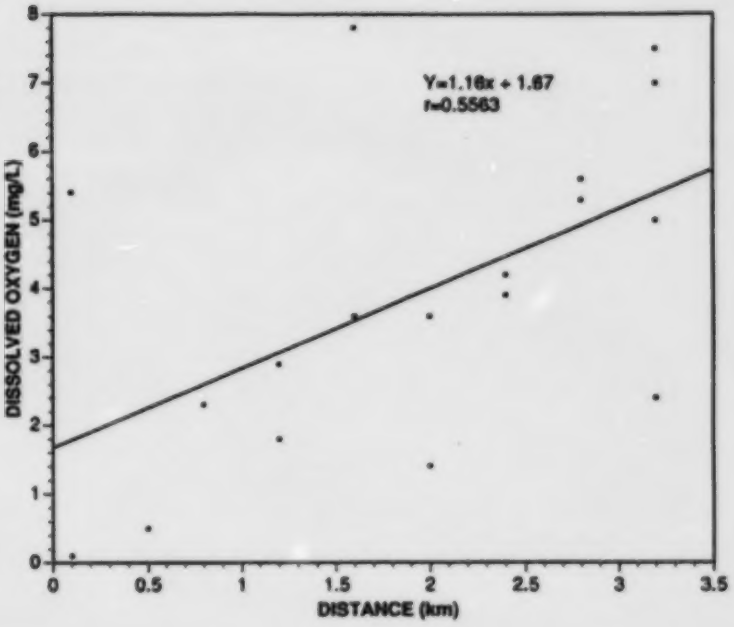


Figure 3: Inverse relationship of Grace Lake winter dissolved oxygen concentrations to distance from the mouth of the sewage lagoon effluent stream.

influence of shallow depths (hence, more tannins from the organic bottom), at stations 1 and 2.

Turbidity may be caused by suspended materials such as clay, silt, fine organic and inorganic matter, algae and microscopic organisms. The mean turbidity of Grace Lake (8.0 units, Table 2) was significantly greater ($t\alpha = 0.05$, Table 3) than that of Montreal Lake (3.69 units, Table 2). Grace Lake turbidity was not directly associated with sewage lagoon discharges as there was not a significant correlation ($r = 0.078$, Table 4) to distance from the mouth of the effluent stream. The greater turbidity of Grace Lake was attributed to the combined influence of greater algae concentrations and a greater burden of suspended sediments. Though not quantified, suspended

sediment values were assumed to be greater on Grace Lake due to fetch (i.e., area unprotected from winds). Shallow lakes with large fetches are prone to suspension of sediments due to wind induced turbulence.

Total Kjeldhal nitrogen (TKN) is a measure of organically bound nitrogen, i.e., the nitrogen that is present in biological material. TKN values may be indicative of the richness of biological productivity or they may be indicative of organic loadings. The mean TKN value for Grace Lake (5.07 mg/L, Table 2) was significantly greater (t_α = 0.05, Table 3) than that of Montreal Lake (1.30 mg/L, Table 2). Correlation to distance from the mouth of the lagoon effluent stream suggested a direct, significant link to sewage discharges (r = 0.406, Table 4). The significant difference in mean TKN values was thus attributed to loadings from the sewage lagoon (Figure 4).

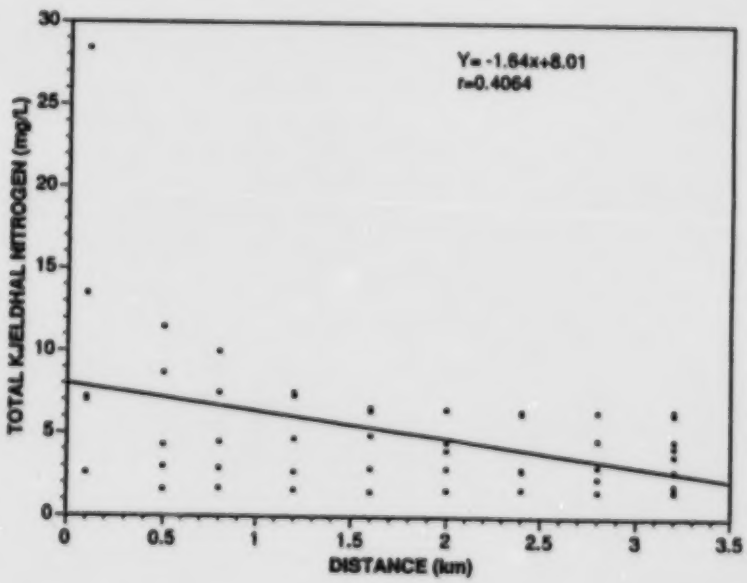


Figure 4: Relationship of Grace Lake total Kjeldhal nitrogen concentrations to distance from the mouth of the sewage lagoon effluent system.

Ammonia is a very effective source of the nutrient nitrogen for plants. As such, ammonia is a relatively unstable compound and, in water, is generally considered a transition stage as organic nitrogen (TKN) decomposes to the dissolved forms such as nitrate. Productive waters with oxygen deficiencies often contain elevated levels of ammonia. Additionally, elevated levels of ammonia are frequently present in sewage treatment system effluents. The mean concentration of ammonia nitrogen in Grace Lake (2.508 mg/L, Table 2) was significantly greater (t_α = 0.05, Table 3) than that of Montreal Lake (0.050 mg/L, Table 2). Additionally, ammonia nitrogen values from Grace Lake were significantly correlated (r = 0.441, Table 4) to distance from the mouth of the lagoon effluent stream (Figure 5). This directly implicated sewage discharges as a significant source of ammonia in Grace Lake.

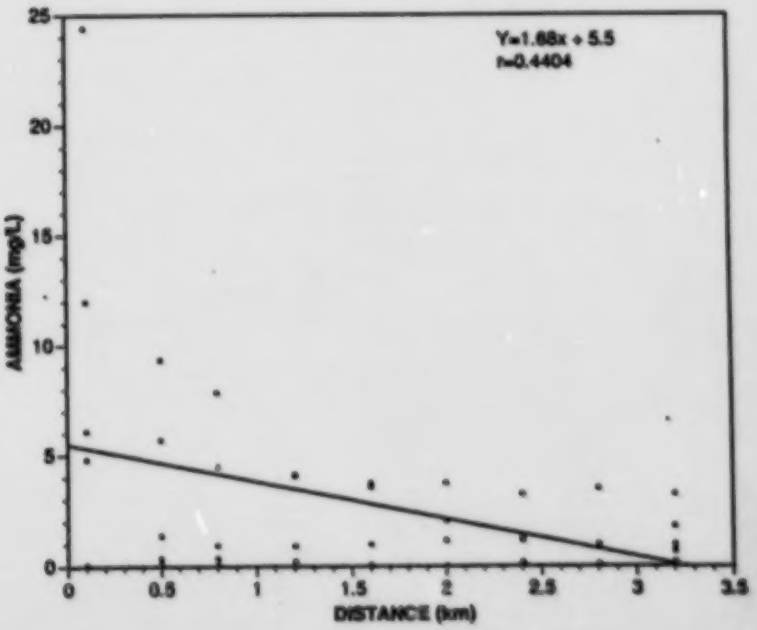


Figure 5: Relationship of Grace Lake ammonia nitrogen concentratrions to distance from the mouth of the sewage lagoon effluent stream.

Dissolved nitrogen is a primary source of the nutrient for most algae and plants. The mean value for Grace Lake (0.12 mg/L, Table 2) was significantly greater ($t_{\alpha} = 0.05$, Table 3) than that of Montreal Lake (0.03 mg/L, Table 2). However, dissolved nitrogen values in Grace Lake were not significantly correlated ($r = 0.013$, TAble 4) to distance from the mouth of the lagoon effluent stream. Thus, lagoon discharges were not a direct source of dissolved nitrogen loadings to Grace Lake.

Generally, phosphorus is the nutrient which most often controls algae and plant growth in aquatic systems (Schindler et al, 1977; Schindler, 1977). Loadings of phosphorus can trigger algae blooms and proliferations of aquatic weeds. Total phosphorus is a measure of both particulate and dissolved forms of phosphorus. Particulate forms include phosphorus that is contained in particles of biological material (example, algae) and in inorganic particles (example, silt). Within aquatic systems, particulate phosphorus serves as a reservoir or source of dissolved phosphorus. Dissolved phosphorus is the form that is directly used by algae and aquatic weeds.

Both mean total phosphorus and mean total dissolved phosphorus values in Grace Lake (0.959 mg/L and 0.748 mg/L, respectively, Table 2) were significantly greater ($t_{\alpha} = 0.05$, Table 3) than those of Montreal Lake (0.064 mg/L, and 0.019 mg/L, respectively; Table 2). Both total and total dissolved forms of phosphorus from Grace Lake were significantly correlated ($r = 0.524$

and 0.553, respectively; Table 4) to distance from the mouth of the lagoon effluent stream (Figures 6 and 7, respectively). This directly implicated sewage discharges as the source of extensive phosphorus loadings to Grace Lake. This meant that excessive growths of both algae and aquatic weeds in Grace Lake were directly linked to discharges from the Town of The Pas sewage lagoon.

Chloride, like sodium, can sometimes be used to trace the path of effluents through aquatic systems. Chloride can also be used to track infiltration by saline groundwater (Meneley, 1987). Mean chloride concentrations in Grace Lake (55 mg/L, Table 2) were significantly greater ($t\alpha = 0.05$, Table 3) than that of Montreal Lake (0.95 mg/L, Table 2).

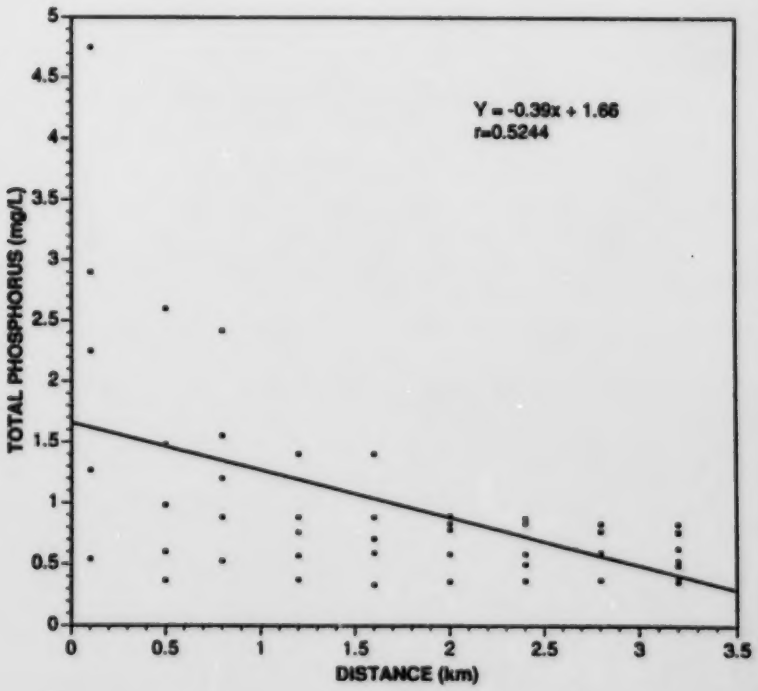
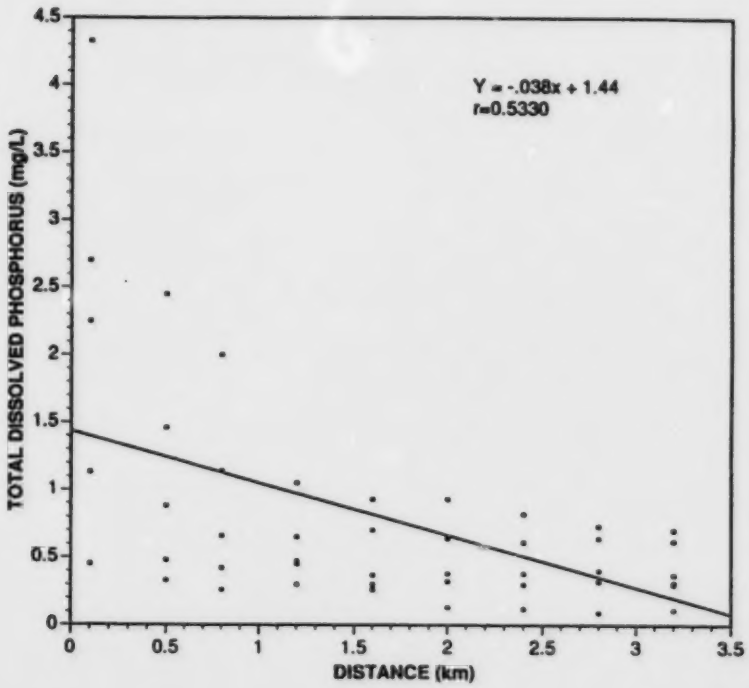


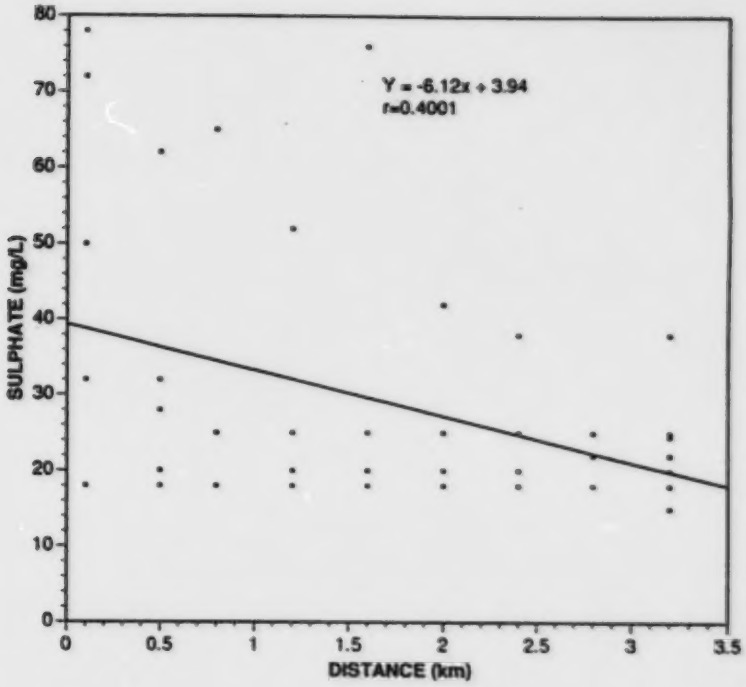
Figure 6: Relationship of Grace Lake total phosphorus concentrations to distance from the mouth of the sewage lagoon effluent stream.



Figire 7: Relationship of Grace Lake total dissolved phosphorus concentrations to distance from the mouth of the sewage lagoon effluent stream.

However, correlation to distance from the mouth of the lagoon effluent stream was not significant ($r = 0.166$, Table 4). This implied that the comparatively elevated chloride concentrations in Grace Lake were not linked to lagoon effluent discharges. Therefore, the primary source of chlorides was probably due to concentration by evaporation and groundwater infiltration from the underlying aquifer. Local well water data presents a wide range of chloride values ranging from 12 mg/L to 1900 mg/L (Appendix VI).

Sulphate may originate primarily from either oxidation of sulphur bearing ores, or from the incomplete decomposition of organic material. Within the present study, sulphates provide an indication of incompletely decomposed organic material. The mean sulphate value for Grace lake (29 mg/L, Table 2) was significantly greater ($t\alpha = 0.05$, Table 3) than that of Montreal Lake (4.6 mg/L, Table 2). Grace Lake sulphate values were



Fugure 8: Relationship of Grace Lake sulphate concentrations to distance from the mouth of the sewage lagoon effluent stream.

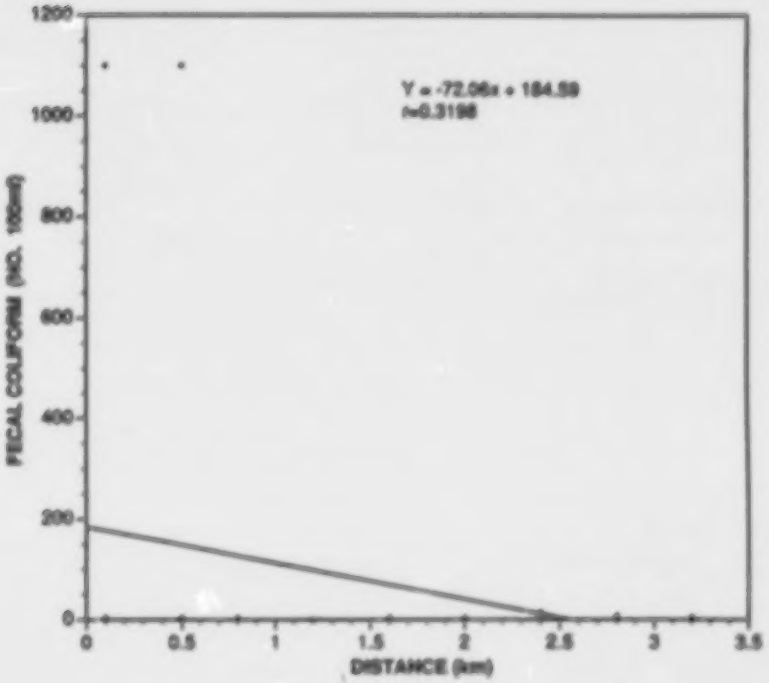
significantly correlated ($r = 0.400$, Table 4) to distance from the mouth of the lagoon effluent stream (Figure 8), thus directly linking the sewage lagoon as a source of sulphate loadings to Grace Lake.

Silicon dioxide is a an essential nutrient for diatoms, an algae which manufactures silica cases to enclose their bodies. Silicon dioxide is not generally linked to sewage discharges; rather it provides an indication of potential for diatom proliferation. The mean value for Grace Lake (13.4 mg/L, Table 2) was significantly greater ($t\alpha = 0.05$, Table 3) than that of Montreal Lake (3.8 mg/L, Table 2),suggesting that Grace Lake was more likely to experience blooms of diatoms than Montreal Lake. As expected, there was not a significant correlation ($r = 0.075$, Table 4) to distance from the mouth of the effluent stream.

Fecal coliform bacteria originate from the intestines of warm blooded animals. They are used as indicators of fecal contamination. Guidelines for recreational uses involving immersion (example, swimming) require that fecal coliform bacteria levels not exceed a geometric mean of 200 organisms/100 ml (Williamson, 1986). Both Grace Lake and Montreal Lake (geometric means of 2.1 organisms/100 ml and 0.1 organisms/100 ml, respectively) easily met the recreational water quality guidelines. Therefore, recreational activities on both lakes were not impaired from a bacteriological perspective. Mean fecal coliform levels on Grace Lake (56.3 organisms/100 ml, Table 2) were not significantly different ($t_{\alpha} = 0.05$, Table 3) from that of Montreal Lake (0.7 organisms/100 ml, Table 2). However, fecal coliform values from Grace Lake were significantly correlated ($r = 0.320$, Table 4) to distance from the mouth of the sewage lagoon effluent stream (Figure 9). This was attributed to a statistical artifact caused by two samples collected in November, 1990. The results of the two samples appeared to be statistical outliers as the values (1100 organisms/100 ml) were much greater than the next nearest value (7 organisms/100 ml). This was considered a reasonable interpretation given that lagoon effluents are disinfected prior to release (N. Pulford, pers. comm.).

Chlorophyll "a" is a pigment which is present in green plants. Water quality studies use chlorophyll"a" measurements to provide an indirect measure of algal abundance. Open water season mean chlorophyll"a" values for Grace Lake (27.1 ug/L, Table 2) were significantly greater

Figure 9: Relationship of Grace Lake fecal coliform levels to distance from the mouth of the sewage lagoon effluent stream.



(t_{α} = 0.05, Table 3) than that of Montreal Lake (15.7 ug/L Table 2). Grace Lake chlorophyll"a" values were not directly linked to lagoon discharges as there was not a significant correlation (r = 0.201, Table 4) to distance from the mouth of the lagoon effluent stream. However, chlorophyll"a" values in Grace Lake were indirectly linked to lagoon discharges in that the effluents were the source of excessive loadings of phosphorus and other nutrients which stimulate algae growth.

4.2 Lake Recovery

Predicting lake recovery is contingent upon developing an accurate estimation of the phosphorus supply and subsequently running the model under various test scenarios.

4.2.1 Present Conditions

The calculation process for the model was itemized (Table 5) and discussed in a step-by-step fashion modified from Hough, Stansbury and Michalski Limited (1980).

Step 1:

The size of the watershed was estimated by standard hydrological procedure (Gray, 1970) wherein the high points of land surrounding the lake were outlined on a 1:50,000 NTS map. It was assumed that both surface water and groundwater flow downhill as indicated by topographic contour lines. The gross drainage area was measured with a planimeter.

Step 2:

Estimation of lake surface area is a standard limnological procedure (Welch, 1948). Surface areas were measured by planimetry on 1:50,000 NTS maps.

Step 3:

The surface area of the lake is excluded from estimations of drainage basin area due to the dynamics of evaporation (Hough, Stansbury and Michalski Limited, 1980).

Step 4:

Mean depth was estimated from a series of soundings taken April 11, 1990.

Step 5:

Estimation of lake volume is a standard limnological calculation (Welch, 1948).

TABLE 5: CALCULATION PROCESS FOR THE GRACE LAKE PHOSPHORUS BUDGET

STEP	PARAMETER	QUANTITATION
1.	Gross Drainage Basin (A)	$2.85 \times 10^7 m^2$
2.	Lake Surface Area (Ao)	$1.06 \times 10^7 m^2$
3.	Drainage Basin (Ad = A-Ao)	$1.79 \times 10^7 m^2$
4.	Lake Mean Depth (Z)	1.68 m
5.	Lake Volume (V = Z· Ao)	$1.78 \times 10^7 m^3$
6.	Net Runoff (r)	0.011 m/yr
7.	Net Annual Evaporation (E_V)*	- 0.271 m/yr
8.	Subsurface Inflow (Q_G = [E_V· Ao] - [Ad· r])	$2.68 \times 10^6 m^3$/yr
9.	Outflow (Q)	$1.49 \times 10^6 m^3$/yr
10.	Flushing Rate (p = Q/V)	0.08 times/yr
11.	Areal Water Load (qs = [Ad·r + Q_G + Q] /Ao)	0.14 m/yr
12.	Retention Coefficient (R = 13.2/13.2 + qs)	0.97
13.	P Loading Rate for Precipitation (L_{Pr})	41 mg/m^2/yr
14.	P Contribution from Precipitation (J_{Pr} = Lpr· Ao)	4.35×10^8mg/yr
15.	P Contribution from Drainage Basin (J_D)	1.84×10^5mg/yr
16.	P Contribution from Sediments During Anoxia (J_S = L_S.Ao.days)	3.07×10^{10}mg/yr
17.	Total P from Sewage Lagoon (J_L)	4.215×10^9mg/yr
18.	P Contribution from Wind Induced Turbulence (J_w = 0.33 J_L + $J_D J_{Pr}$)	1.53×10^9mg/yr
19.	Total P Supply (J_T = J_{Pr} + J_d + J_s + J_L + J_w)	3.689×10^{10}mg/yr
20.	Predicted Spring Total P Concentration (P = J_T (1-R) /Q)	742.8 mg/m^3

* Net evaporation rate is the excess of evaporation over precipitation.

Step 6:

Net runoff for the area has been estimated by the standard hydrological expression $r = Q/Ad$, (Gray, 1970), using data from the Overflowing River, where $Q = 3.88 \times 10^7$ m^3 and $Ad = 3.53 \times 10^9$ m^2 (Inland Waters Directorate, 1987).

Step 7:

Estimates of the net annual evaporation rate for Grace Lake were provided by A. Warkentin* (pers. comm.)

Step 8:

Given that net annual runoff for the watershed (i.e., $Ad.r = 1.97 \times 10^5$ m^3) is less than net annual losses due to evaporation from the lake surface (i.e., $E_V \cdot Ao = 2.87 \times 10^6$ m^3), water levels could only be maintained in the lake if significant subsurface inflows (i.e., Q_G) occurred to balance the evaporation losses. The rate of subsurface inflow required to maintain static lake levels under natural conditions (i.e., prior to construction of the dyke and prior to sewage lagoon discharges) may be estimated as equivalent to the difference between inputs due to annual runoff and losses due to mean annual evaporation (i.e., $Q_G = (E_v \cdot Ao) - (Ad \cdot r)$). This estimate of Q_G is considered reasonable since lesser flows would result in the drying up of Grace Lake and greater flows would have resulted in an outflowing stream. The case for greater outflows cannot be suported as 1:50,000 NTS maps fail to indicate the presence of a natural outflow channel.

Subsurface inflows probably consist of groundwater (i.e., water

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* A. Warkentin, Hydrometeorologist, Water Resources Branch; Manitoba Department of Natural Resources.

originating from an aquifer) and lateral percolation through the shallow peats which about the easterly and southerly shores of Grace Lake. Using estimates of the hydraulic gradient and hydraulic conductivity of glacial tills underlying Grace Lake, calculations of groundwater inflow rates range from 1.5 to 16 cm/yr. (R. Betcher,* pers. comm.). A study from North Shoal Lake in southern Manitoba, also underlain by similar tills, indicated groundwater inflow was as much as 33 cm/yr. (Goff, 1971). However, much of this inflow was thought to be through springs and flowing wells, an unknown situation in the Grace Lake basin. Using 16 cm/yr., the total annual loading from groundwater would be 1.7×10^6 cubic metres. The remainder, 9.79×10^5 cubic metres, must originate from lateral percolation. Betcher (pers. comm.) further advises that this estimate for lateral percolation appears to be high due to the flat topography in the area and may be inflated due to the uncertainty in other estimates such as r.

Step 9:

Step 8 concluded that the sum of inflows from the watershed and the subsurface was equivalent to evaporation losses. Thus, any outflow which might occur would be attributable to loadings from the sewage lagoon. The estimate provided was derived from information forwarded by N. Fulford (Section 2.3.1)

Steps 10 and 11:

These calculations are standard load estimation procedures (Hough, Stansbury and Michalski Limited, 1980). However, the calculation of qs has been modified to include all inflows to the lake.

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* R.N. Betcher, Aquifer Definition Geologist, Water Resources Branch, Manitoba Department of Natural Resources.

Step 12:

The empirical formula for estimating the relative amount of phosphorus unavailable for dispersion through the water column was provided by Dillon in Hough, Stansbury and Michalski Limited (1980). The equation replaces that proposed by Dillon and Kirchner (1975).

Steps 13 and 14:

Atmospheric contribution of phosphorus can be very significant in lakes with small drainage basins (Schindler et al, 1978). Values reported by Schindler et al (1978) range from 24 to 53 mg/m^2/year for the Experimental Lakes Area near Kenora, Ontario. Experimental measurements of aeolian phosphorus contributions conducted near Brandon, Manitoba indicated loading rates ranging from 0.3 to 82 mg/m^2/year (M. Bennett, pers. comm.*). It was deemed reasonable to adopt the arithmetic mean of the Brandon value (i.e., $41/m^2$/year) for the present study due to its geographic location. Estimation of the total atmospheric contribution to Grace Lake was calculated as the rate per square metre multiplied by total surface area of the lake.

Step 15:

The phosphorus concentrations of inflows from surface runoff and the subsurface were not measured due to the limited degree of development influencing Grace Lake. Additionally, loadings from nearby septic fields of residences located adjacent to the dyke were not expected to occur due to ditching along the external edge of the dyke that would intercept any shallow lateral flows. Rather, the mean phosphorus value for Montreal Lake (i.e., P_m = 0.064 mg/L; Table 2) was adopted as being indicative of the natural mean

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* M. Bennet, Special Projects Coordinator, Air Standards and Studies, Manitoba Department of Environment and Workplace Safety and Health.

for the area. Accordingly, the phosphorus contribution from the drainage basin (i.e., J_D) was estimated by the expression $J_D = P_m (Q_G + Ad.r)$.

Step 16:

Vollenweider (1975), Dillon (1975), and Nurnberg (1984) report that a net release of phosphorus occurs from lake sediments during anoxia. A mean of Vollenweider's (1975) estimates of daily phosphorus releases from sediments (L_s = 9.5 mg/m^2/day) has been adopted for the present study. Because of the variability in the onset of bottom anoxia, the average duration of anoxic conditions could only be estimated. On the basis of elevated iron and manganese values (Appendix V), it was assumed that bottom anoxia would occur during all months except June and September. Thus, bottom anoxia was assumed to occur on average about 305 days per year.

Step 17:

The total phosphorus contributed by effluent from the Town sewage lagoon during 1990 was estimated by the expression $J_L = V_L \cdot P_L$;

where J_L = total phosphorus (mg) from the lagoon effluent discharge during 1990;

V_L = volume (L) discharged during 1990;

P_L = mean phosphorus concentration (mg/L) of the 1990 lagoon effluent.

The estimate of V_L(4,095 cubic metres per day) was derived from information provided by N. Fulford (Section 2.3.1). The estimate of (P_L) (2.82 mg/L) was derived from the mean phosphorus value for station G-1 (Appendix V).

Step 18:

Wind induced turbulence in shallow lakes (< 3.0 m deep) can readily suspend surficial sediments, thereby elevating the water column total phosphorus concentration (De Groot, 1981). De Groot (1981) suggests that over the long term approximately two-thirds of the gross external phosphorus loading settles.

Steps 19 and 20:

Calculations were performed according to formulae presented by Hough, Stansbury and Michalski Limited (1980).

Under existing conditions, the spring total phosphorus concentration for Grace Lake was predicted to be 742.8 mg/m^3 (Table 5). The mean total phosphorus concentration observed during April 1990 was 1354 mg/m^3 (from Appendix V(ia)*. The difference between predicted and observed values suggested that the value of the Retention Coefficient (R = 0.97) had been overestimated (Step 12; Table 5). However, adopting an R value of 0.945 would yield a predicted spring total phosphorus concentration of 1361.8 mg/m3 (per step 20; Table 5) which is similar to the observed value. Thus, it was inferred that the Grace Lake posphorus budget (Table 5) was valid as presented except for the original estimate of R.

The flushing rate (p) under existing conditions was estimated at 0.08 times per year (Step 10; Table 5). Under present rates of hydraulic loading, the water of Grace Lake would theoretically be replaced once every 12.5 years (1/p).

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* Water concentration values, expressed in mg/L, have been converted to mg/m^3 (i.e.,multiplied by 1000) for the sake of consistency with the calculation process.

4.2.2 Predicted Conditions Assuming No Discharge From Sewage Lagoon

Change in water quality is contingent upon two primary variables. These variables are the quality of inflowing waters, and the rate at which water is replaced or flushed.

This option assumes that sewage lagoon effluent will no longer be discharged to Grace Lake thereby eliminating an annual loading of 4.215 tonnes of phosphorus (Step 17; Table 5) and an annual hydraulic loading of 1.49×10^6 m^3 of water (Step 9; Table 5).

The outflow from Grace Lake was estimated as equivalent to hydraulic loading from sewage lagoon discharges (Step 9; Table 5). Therefore, elimination of hydraulic loading from the sewage lagoon will result in the cessation of outflows from Grace Lake. This lack of an outflow would prevent flushing of the lake and would preclude lake renewal. Water quality and biological productivity would then be controlled by internal recycling of the existing nutrient supply and would cause Grace Lake to stagnate. The water quality would not improve under this option.

4.2.3 Predicted Conditions Assuming Reduced Phosphorus Discharges

This option assumes that sewage lagoon effluent would continue to be discharged to Grace Lake, but that the phosphorus concentrations of the effluent would be reduced. Two phosphorus models were developed. The first (Table 6) was predicated on typical results (i.e., phospshorus concentrations of 1.0 mg/L) for standard phosphorus reduction technologies. This corresponded to a 67% reduction in the effluent's phosphorus concentration.

TABLE 6: PREDICTION OF PHOSPHORUS CONCENTRATIONS IN GRACE LAKE ASSUMING A 67% REDUCTION IN PHOSPHORUS CONTENT OF THE LAGOON EFFLUENT

STEP	PARAMETER	QUANTITATION
1.	Gross Drainage Basin (A)	$2.85 \times 10^7 m^2$
2.	Lake Surface Area (Ao)	$1.06 \times 10^7 m^2$
3.	Drainage Basin (Ad = A-Ao)	$1.79 \times 10^7 m^2$
4.	Lake Mean Depth (Z)	1.68 m
5.	Lake Volume (V = Z· Ao)	$1.78 \times 10^7 m^3$
6.	Net Runoff (r)	0.011 m/yr
7.	Net Annual Evaporation (E_V)	- 0.271 m/yr
8.	Subsurface Inflow $Q_G = [E_V \cdot Ao] - [Ad. r]$	$2.68 \times 10^6 m^3/yr$
9.	Outflow Q	$1.49 \times 10^6 m^3/yr$
10.	Flushing Rate (p = Q/V)	0.08 times/yr
11.	Areal Water Load (qs = $[Ad.r + Q_G + Q]$ /Ao)	0.14 m/yr
12.	Retention Coefficient (R = 13.2/13.2 + qs)	0.945
13.	P Loading Rate for Precipitation (L_{Pr})	$41. mg/m^2/yr$
14.	P Contribution from Precipitation (J_{Pr} = Lpr.Ao)	$4.35 \times 10^8 mg/yr$
15.	P Contribution from Drainage Basin (J_D)	$1.84 \times 10^5 mg/yr$
16.	P Contribution from Sediments During Anoxia ($J_S = L_S$.Ao.days)	$3.07 \times 10^{10} mg/yr$
17.	Total P from Sewage Lagoon (J_L)	$1.49 \times 10^9 mg/yr$
18.	P Constribution from Wind Induced Turbulence ($J_w = 0.33 \ J_L + J_{DJPr}$)	$6.35 \times 10^8 mg/yr$
19.	Total P Supply ($J_T = J_{Pr} + J_d + J_s + J_L + J_w$)	$3.326 \times 10^{10} mg/yr$
20.	Predicted Spring Total P Concentration ($P = J_T (1-R) \ /Q$)	$1227.7 mg/m^3$

TABLE 7: PREDICTION OF PHOSPHORUS CONCENTRATIONS IN GRACE LAKE ASSUMING A 75% REDUCTION IN PHOSPHORUS CONTENT OF THE LAGOON EFFLUENT

STEP	PARAMETER	QUANTITATION
1.	Gross Drainage Basin (A)	$2.85 \times 10^7 m^2$
2.	Lake Surface Area (Ao)	$1.06 \times 10^7 m^2$
3.	Drainage Basin (Ad = A-Ao)	$1.79 \times 10^7 m^2$
4.	Lake Mean Depth (Z)	1.68 m
5.	Lake Volume ($V = Z \cdot Ao$)	$1.78 \times 10^7 m^3$
6.	Net Runoff (r)	0.001 m/yr
7.	Net Annual Evaporation (E_V)	- 0.271 m/yr
8.	Subsurface Inflow ($Q_G = [E_V \cdot Ao] - [Ad.r]$)	$2.68 \times 10^6 m^3/yr$
9.	Outflow (Q)	$1.49 \times 10^6 m^3/yr$
10.	Flushing Rate ($p = Q/V$)	0.08 times/yr
11.	Areal Water Load ($qs = [Ad \cdot r + QG + Q] /Ao$)	0.14 m/yr
12.	Retention Coefficient ($R = 13.2/13.2 + qs$)	0.945
13.	P Loading Rate for Precipitation (L_{pr})	$41 mg/m^2/yr$
14.	P Contribution from Precipitation ($J_{pr} = Lpr.Ao$)	$4.35 \times 10^8 mg/yr$
15.	P Contribution from Drainage Basin (J_D)	$1.84 \times 10^5 mg/yr$
16.	P Contribution from Sediments During Anoxia ($J_S = L_S.Ao.days$)	$3.07 \times 10^{10} mg/yr$
17.	Total P from Sewage Lagoon (JL)	$9.27 \times 10^8 mg/yr$
18.	P Contribution from Wind Induced Turbulence ($J_w = 0.33(J_L + J_D J_{Pr}$	$3.06 \times 10^8 mg/yr$
19.	Total P Supply ($J_T = J_{Pr} + J_d + J_s + J_L + J_w$)	$3.237 \times 10^{10} mg/yr$
20.	Predicted Spring Total P Concentration ($P = J_T (1-R) /Q$	$1194.9 mg/m^3$

The second (Table 7) was based on mean phosphorus concentrations near the outlet of Grace Lake (i.e., 0.622 mg/L, Station 10 as per Appendix V). This corresponded to a 75% reduction in the effluent's phosphorus concentration. These assumptions were considered representative of readily achievable results and of best existing quality, respectively.

The first scenario, with an assumed 67% reduction in the phosphorus concentration of the effluent, resulted in a predicted spring total phosphorus concentration of 1227.7 mg/m3 for Grace Lake (Table 6). This represented a 10% reduction in mean spring concentrations for Grace Lake. The flushing rate for this scenario (i.e., p, Step 10; Table 6) suggests that the maximum improvement in water quality would be achieved in apporoximately 12.5 years (i.e, 1/p).

The second scenario, with an assumed 75% reduction in the phosphorus concentration of the effluent, resulted in a predicted spring total phosphorus concentration of 1194.9 mg/m^3 for Grace Lake (Table 7). This represented a 13% reduction in mean spring concentrations for Grace Lake. The flushing rate for this scenario (i.e., p, Step 10, Table 7) suggests that the maximum improvement in water quality would also be achieved in approximately 12.5 years (i.e., 1/p).

4.3 Disposal Options

Options for disposal of sewage lagoon effluent may be grouped into two categories. These are those options involving continued discharge to Grace lake, and, options involving discharge elsewhere.

4.3.1 Options With Continued Discharge to Grace Lake

Continued discharge of effluent to Grace Lake offers two basic approaches. These are no modification of current practice, and adoption of some technique to mitigate the problem. Mitigation must focus on phosphorus removal or deactivation, since phosphorus was identified as the primary cause of poor water quality in Grace Lake (Section 4.1). Phosphorus removal or deactivation may be accomplished either in the sewage lagoon or in Grace Lake. There are at least three options involving continued discharge to Grace Lake; no modification, lagoon treatment and lake treatment.

The "no modification" option represents the status quo. This option offers considerable financial advantage since neither new capital expenditures nor additional operating and maintenance costs are required. However, neither deteriorating water quality conditions on Grace Lake nor public concerns about the issue would be addressed. Therefore, it is recommended that the "no modification" option be eliminated.

The "lagoon treatment" option may involve the application of a chemical (e.g., alum) which settles phosphorus from the water or it may involve an extended lagoon-wetland complex where plants biologically extract phosphorus from the water. A combination of the two processes may also provide phosphorus reduction. Chemical treatment requires moderate operating expenses for the purchase and application of materials. Additionally, a second lagoon cell may be required in order to provide sufficient retention time for efficient and effective phosphorus removal. Development of an extensive lagoon-wetland complex may be capital intensive but operating costs

are negligible. The system would also be very efficient at phosphorus removal. Given that the various configurations of the "lagoon treatment" option can effectively remove phosphorous without extremely high costs, it warrants further evaluation.

The "lake treatment" option entails the application of an appropriate chemical over the entire surface area of Grace Lake in order to settle phosphorus from the water. Calcium carbonate (lime) and calcium hydroxide (slaked lime) are the two chemicals most commonly used. The key to long-term effectiveness is sediment retention of the settled phosphorus. However, the large surface area and shallow depth of Grace Lake render upper layers of sediment susceptible to suspension by wind induced turbulence. This would negate any benefits from chemical treatment. Hence, it is recommended that the "lake treatment" option be eliminated.

4.3.2 Options With Discharge Elsewhere

Three alternate approaches for disposal of sewage lagoon effluent were identified. These approaches are discharge to a waterbody other than Grace Lake, deep well injection, and farmland irrigation. Alternate waterbodies located relatively near the sewage lagoon, listed in order of proximity, include The Saskatchewan River, Cemetary Lake and Montreal Lake. Thus, there are a total of five options identified which involve discharge of sewage lagoon effluent elsewhere than to Grace Lake.

Discharge to the Saskatchewan River entails transporting the effluent approximately 2.55 kilometres (direct distance) from the lagoon. Typically such transport is achieved by construction of either an open ditch

or a pipeline. A second critical consideration includes effects of the discharge upon Saskatchewan River water quality.

Discharge to Cemetary Lake involves transporting the effluent approximately 3.05 kilometres (direct distance) from the lagoon. As with the Saskatchewan River discharge option, effluent transport might be achieved by either an open ditch or a pipeline. Construction costs are likely to be greater than the "Saskatchewan River discharge" option since the route would be at least 17% longer. Operating and maintenance expenses are also likely to be more, since pumping from the lagoon would probably be required to compensate for the slightly greater elevation of Cemetary Lake. However, environmental impacts may be beneficial since the emergent vegetation, predominantly cattail, covering Cemetary Lake would probably be enhanced. This would probably improve habitat for rearing waterfowl and for aquatic furbearers such as muskrat. Additionally, excess nutrients would be stripped from the effluent by the emergent vegetation.

The Montreal Lake discharge option requires transport of the effluent approximately 5.1 Kilometres (direct distance) from the lagoon. Hence, all relevant costs are likely to be at least twice as great as those of the Saskatchewan River discharge option. Given the physical and hydrological similarities between Grace Lake and Montreal lakes, discharge of sewage lagoon effluents to Montreal Lake is likely to rapidly induce eutrophic conditions very similar to those now occurring at Grace Lake. Thus, adoption of the Montreal Lake discharge option would address the public concern by means that are very costly from both financial and environmental perspectives. Accordingly, it is recommended that this option be rejected from further consideration.

Deep well injection requires a deep underground formation capable of accepting high volumes of liquid. Generally, such acceptance is contingent upon withdrawals of fluid such as might occur at an oilfield. Appropriate formations are not known to occur in the vicinity of The Pas. Indeed, the salinity of the town's auxiliary fire wells (wells 1A and 1B, Appendix VI) may be an indication that the area is underlain by the same highly pressurized saline aquifer that Meneley (1987) described in the Namew Lake area. Injections to such aquifers are not practical given the volume of effluent discharged from The Pas sewage lagoon. Thus, it is recommended that the "deep well injection" option be rejected.

Irrigation of farmland with lagoon effluent requires a delivery system, lands and crops capable of accepting the irrigation without harm and landowners willing to accept the effluent. Irrigation delivery systems typically are capital intensive. Additionally, a fairly extensive system would be required for delivery of the volume of effluent generated by The Pas. Serious difficulties with freezing could be expected to occur during winter months. Most agricultural lands near The Pas currently are poorly drained and require extensive ditching to maintain arability. Clearly, excess moisture is an ongoing problem for the area. The willingness of local landowners to accept irrigation by sewage effluent has not been canvassed. Very high capital costs, difficulties in winter operation and poor drainage of local agricultural lands lead to the recommendation that the agricultural irrigation option be rejected.

4.3.3 Evaluation of Options

Options retained for further evaluation included lagoon treatment, Saskatchewan River discharge and Cemetary Lake discharge. Major criterion by which these options could be evaluated were cost and the potential for achieving improvement in the water quality of Grace Lake. However, elimination of lagoon discharges will not result in improved water quality conditions in Grace Lake (Section 4.2.2). Furthermore, partial recovery of Grace Lake is contingent upon additional hydraulic loading such as discharges of treated lagoon effluent (Section 4.2.3). Thus, irrespective of comparative costs, the lagoon effluent treatment option was allotted preferred status because it was only option with the potential for improving water quality conditions in Grace Lake.

4.4 AQUIFER CONTAMINATION

Contamination of the local aquifer by infiltration of water from Grace Lake to the aquifer theoretically should be evidenced by elevated levels of certain chemical variables in wells near Grace Lake and by reduced levels of these chemical variables in wells further away from Grace Lake. However, with one exception, correlations of well water chemistry to distance from Grace Lake (Table 8) failed to indicate the occurrence of any significant negative correlations. (A significant positive relationship would suggest cleaner groundwater near Grace Lake.) The one exception, sulphate, appeared to be a statistical artifact since the mean value for Grace Lake (29 mg/L) was less than the mean value in wells located within 200

metres of Grace Lake (40 mg/L). The results implied that a significant amount of water from Grace Lake was not infiltrating to the underlying aquifer. Indeed, estimates of hydraulic loading to Grace Lake (Steps 8 - 10, Table 5) suggested that Grace Lake receives seepage from the underlying aquifer. Further, Betcher (pers. comm.), interpeting Pederson's (1973) work, advises that the potential for groundwater contamination "could have been dismissed almost out of hand" due to an upward hydraulic gradient of approximately 5% and a 30 meter layer of till which separates the lake from the underlying carbonate rock aquifer. It was therefore concluded that the direction of groundwater flow is upwards from the aquifer into Grace Lake and that the quality of water in Grace Lake did not influence the quality of water in local wells.

TABLE 8: CORRELATIONS ($t_\alpha = 0.05$) OF LOCAL WELL WATER CHEMISTRY TO DISTANCE (m) FROM CRACK LAKE

Parameter	Correlation Coefficient	Statistical Significance	Slope Direction	Level of Significance
Conductivity	0.007	No	-	-
pH	0.094	No	-	-
Total Alkalinity	0.137	No	-	-
Bicarbonate Alkalinity	0.142	No	-	-
Calcium	0.014	No	-	-
Magnesium	0.022	No	-	-
Hardness	0.004	No	-	
Manganese	0.325	Yes	Positive	98.1
Iron	0.151	No	-	-
Sodium	0.009	No	-	-
Fluoride	0.207	No	-	-
Nitrate	0.039	No	-	-
Chloride	0.018	No	-	-
Sulphate	0.297	Yes	Negative	97.5%

5.0 CONCLUSION

It was concluded that:

1. Discharges from the Town of The Pas sewage lagoon directly resulted in the following changes to Grace Lake water quality:
   - depressed dissolved oxygen concentrations,
   - elevated concentrations of organically bound nitrogen,
   - elevated ammonia concentrations,
   - elevated total phosphorus concentrations,
   - elevated total dissolved phosphorus concentrations, and
   - elevated sulphate concentrations.
2. Discharges of nutrients from the Town of The Pas sewage lagoon stimulated excessive algae blooms and the proliferation of aquatic weeds in Grace Lake.
3. Although fecal coliform bacteria levels are within guidelines established for primary recreational activities, aesthetic considerations such as excessive algae blooms and extensive weed growth impair recreational opportunities which might involve body contact with the water.
4. Although sewage lagoon discharges are the primary source of external phosphorus loading to Grace Lake, it is internal recycling of phosphorus already present in the lake that is now the dominant factor controlling algae and weed growth.
5. Grace Lake water quality would not change if lagoon discharges to the lake were halted because there would be insufficient inflows to flush the lake.

6. Over a period of approximately 12.5 years, the water quality of Grace Lake would improve marginally if lagoon effluents were to receive treatment for phosphorus removal prior to their discharge to Grace Lake.

7. Treatment for phosphorus removal prior to lagoon effluent discharge to Grace Lake was the only option with some potential to cause an improvement in the water quality of Grace Lake.

8. Grace Lake was not contaminating the local aquifer.

6.0 RECOMMENDATION

It was recommended that the lagoon effluent treatment option be given consideration as an effluent disposal option.

7.0 REFERENCES CITED

Barica, 1977. Effect of freeze-up on major ion and nutrient content of a prairie winter kill lake. J. Fish. Res. Board. Can. 34:2210-2215.

Beck, A.E. 1988. Nutrient Enrichment Study of Shoal lake (Western Manitoba). Water Standards and Studies Report No. 88-3. Manitoba Department of Environment and Workplace Safety and Health. Winnipeg. 67 pp.

Carlson, R.E. 1977. A trophic state index for lakes. Limnol. Oceanogr. 22:361-369.

Davies, J.F., B.B. Bannatyne, G.S. Barry and H.R. McCabe. 1962. Geology and Mineral Resources of Manitoba. Mines Branch, Manitoba Department of Mines and Natural Resources. Winnipeg. 190 pp.

De Groot, W.T. 1981. Phosphate and wind in a shallow lake. Arch. Hydrobiol. 91:475-489.

Dillon, P.J. and W.B. Kirchner. 1975. The effects of geology and land use on the export of phosphorus from watersheds. Water Res. 9: 135-148.

Goff, K.J. 1971. Hydrogology and chemistry of the Shoal Lakes Basin, Interlake Area, Manitoba. A thesis submitted to the Faculty of Graduate Studies in partial fulfillment of the requirements for the degree of Master of Science. University of Manitoba. Winnipeg. 112 pp.

Gray, D.M. (ed.) 1970. Handbook on the principles of hydrology. National Research Council of Canada. Water Information Centre, Inc. Port Washington, N.Y.

Hough, Stansbury and Michalski Limited. 1980. An evaluation of methods to assess the effects of shoreline development on lake trophic state. Prepared for Ontario Ministry of Natural Resources, March 1980 Hough, Stansbury and Michalski Limited. Rexdale, Ontario. 123 pp and app.

Inland Waters Directorate. 1987. Historical streamflow summary: Manitoba; to 1986. Water Resources Branch, Water Survey of Canada. Ottawa. 275 pp.

Meneley, W.A. 1987. Hydrogeology of the Namew Lake area. A Report prepared for the Hudson Bay Mining and Smelting Co. Limited. W.A. Meneley Consultants Ltd. Saskatoon. 18 pp and app.

Nurnberg, G.K. 1984. The prediction of internal phosphorus load in lakes with anoxic hypolimnia. Limnol. Oceanogr. 29:111-124.

Pedersen, A. 1973. Groundwater availability in The Pas area. Groundwater availability studies Report No. 9. Water Resources Branch, Manitoba Department of Natural Resources, Winnipeg. 32 pp and figures.

Schindler, D.W. 1977. Evolution of phosphorus limitation in lakes. Science (Wash., D.C.) 195:260-262.

Schindler, D.W., F.A.J. Armstrong, S.K. Holmgren and G. J. Brunskill. 1977. Eutrophication of Lake 227, Experimental Lakes Area, Northwestern Ontario, by addition of phosphate and nitrate. J. Fish. Res. Board Can. 28:1763-1782.

Schindler, D.W., E.J. Fee and T. Rusczynski. 1978. Phosphorus input and its consequences for phytoplankton standing crop and production in the Experimental Lakes Area and in similar lakes. J. Fish. Res. Board Can. 35:190-196.

Sorba, E.A., D. Fox and P. Douvill. 1980. Analytical methods, 2nd ed. Technical Services Laboratory. Manitoba Department Mines, Natural Resources and Environmental Management. Winnipeg.

Underwood, McLellan and Associates Limited. 1972. Groundwater investigation and waterwell construction for the Town of The Pas, The Pas, Manitoba, 1972. The UMA Group. 1479 Buffalo Place, Winnipeg. 29 pp + Tables and Plates.

Vollenweider, R. A. 1975. Input-output models, with special reference to the phosphorus loading concept in limnology. Schweiz. Zeit. Hydrol. 37:53-84.

Water Resources. 1990. Grace Lake Water Level Management. Compiled for the Grace Lake Water Quality Management Board. Manitoba Natural Resources. Dauphin. 20 pp + chart.

Weir, T.R. (ed.). 1983. Atlas of Manitoba. Surveys and Mapping Branch, Manitoba Natural Resources. Winnipeg. 157 pp.

Welch, P.S. 1948. Limnological Methods. The Blakiston Co. Toronto. 381 pp.

Williamson, D.A. 1986. Manitoba surface water quality objectives. Water Standards and Studies Report. Environmental Management Division. Manitoba Department of Environment and Workplace Safety and Health. Winnipeg. 46 pp.

8. 0 ACKNOWLEDGEMENTS

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LIST OF APPENDICES

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- (v) January 29, 1991

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- (ia) Grace Lake, April 11, 1990
- (ib) Montreal Lake, April 11, 1990
- (iia) Grace Lake, June 19, 1990
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VI Chemistry of Well Water from the Grace Lake Area.

VII Metric Conversion

AN ORDER OF THE CLEAN ENVIRONMENT COMMISSION

UNDER THE CLEAN ENVIRONMENT ACT

Re: The Clean Environment Commission and the Town of The Pas, applicant,

WHEREAS pursuant to the provisions of The Clean Environment Act, the Town of The Pas has submitted an application to the Clean Environment Commission requesting the Commission to prescribe limits in connection with the operation of an existing aerated sewage lagoon system located in NW¼ Section 2, Township 56, Range 26 W.P.M. at The Pas, Manitoba

AND WHEREAS no representation was made to the Clean Environment Commission by any person who is or is likely to be affected by an Order of the Commission prescribing limits in connection with the said operation,

AND WHEREAS the Clean Environment Commission considered the application on the 9th day of October, 1973,

IT IS HEREBY ORDERED THAT

1. The applicant shall ensure that all the facilities for the treatment of sewage and the holding of effluent are maintained and operated in such a manner as to prevent the contamination of groundwater,

2. The applicant shall ensure that said sewage lagoon system is operated in such a manner as to minimize the release of offensive odours,

3. The applicant shall ensure that the biochemical oxygen demand loading of the said aerated sewage lagoon system does not exceed 2,250 pounds per day (population equivalent 15,000),

4. The applicant shall ensure that the quality of the final effluent from said aerated sewage lagoon system is such that:

   (a) the biochemical oxygen demand does not exceed 30 milligrams per litre and,

   (b) there is a combined chlorine residual of 0.5 milligrams per litre of sample after 15 minutes of contact.

Order No. 330

Dated at the City of Winnipeg
this 13th day of December 1973

G. S. Moore

Chairman,
Clean Environment Commission

C-b-144.3

APPENDIX II

COMPOSITION OF THE GRACE LAKE WATER QUALITY MANAGEMENT BOARD

Chairperson	Steve Davis, Regional Supervisor, Department of Environment.
Technical Advisor	Al Beck, Environment Officer, Department of Environment
Recorder	Wendy Ralley, Environment Officer, Department of Environment
Member	Larry King, Councillor, Local Government District of Consol
Member	Jim Lamontagne, Councillor, Local Government District of Consol
Member	Nelson Fulford, Municipal Superintendent, Town of The Pas
Member	John Pondse/Don Allen, Manager, Beaver Air Service, Grace Lake
Member	Murray Harvey, Representative of "Friends of Grace Lake"
Member	John Towle, Regional Water Manager, Water Resources Branch
Member	Bob Huck, Regional Superintendent, Department of Natural Resources
Member	Bob Uchtmann, Marsh Manager, Department of Natural Resources
Member	Craig Hanley, Senior District Planner, Department of Rural Development

APPENDIX III

TERMS OF REFERENCE FOR THE GRACE LAKE WATER QUALITY MANAGEMENT BOARD

1. Examine the implications of increased resource use among the various groups.

2. Examine the implications of residential development on the aquifer recharge system for Grace Lake.

3. Review criteria for lake level management and dyke maintenance.

4. Examine the implications of various sewage disposal options.

5. Determine the extent to which the water quality of Grace Lake will recover if sewage discharge is discontinued.

6. Examine the impact of Town of The Pas sewage lagoon discharges upon the water quality of Grace Lake.

7. Review present and future land use zoning.

APPENDIX IV

MINUTES OF MEETINGS OF THE CRACK LAKE WATER QUALITY MANAGEMENT BOARD

NOTE

Original minutes have been edited so as to correct the errors and omissions identified at subsequent meetings. Minute appendices such as data tables and figures that are reproduced elsewhere in the report have been excluded. The list of absentee members has likewise been excluded from each set of minutes. Grammatical and typographical errors occurring in original minutes have been corrected.

APPENDIX IV (1)

GRACE LAKE WATER QUALITY MANAGEMENT BOARD - MINUTES - MEETING - APRIL 10, 1990 - THE PAS

The meeting was convened at 7:00 P. M. with the following participants.

Steve Davis	-	Chairman/Department of Environment
Al Beck	-	Environment Officer/Department of Environment
John Towle	-	Regional Water Manager/Water Resources
Nelson Fulford	-	Municipal Superintendent/Town of The Pas
Bob Buck	-	Regional Superintendent/Department of Natural Resources
Jim Lamontagne	-	Councillor/Local Government District of Consol
Larry King	-	Councillor/Local Government District of Consol

A brief introduction of the purpose and role of the Board and the intention to focus on water quality issues of Grace Lake was outlined. The Department of Environment is aware that there has been a history of complaints and concerns by many people about Grace Lake. There is also a history of requests for various studies of the Lake to be done with an anticipation of reviewing and resolving some of the issues. As a result, this Board was convened to develop a lake management plan based on environmental issues. The 5 agenda items were discussed as follows:

1. Establish Terms of Reference for the Board

(i) A list of 7 suggested terms of reference were reviewed with several changes and additions made.

(ii) A list of ten uses of the lake and surrounding area were discussed.

(a) Private Flying Club
(b) Commercial Flying Business
(c) Proposed Bird Sanctuary
(d) Receiving water for treated municipal sewage
(e) Trapping
(f) Wildrice (not presently done)
(g) Hunting
(h) Recreational
(i) Dog Kennel Area
(j) Residential

(iii) Nelson Fulford asked if it was possible to review the history of Grace Lake. John Towle pointed out that his Branch has a good record of this project and John would gather the information and forward to each Board Member.

(iv) John Towle pointed out that Grace Lake water levels are regulated, but recent drought years have resulted in not attaining the high end of the regulated water level. Mutual consent by users has led to establishment of an appropriate regulated level.

(v) Bob Huck indicated that Murray Harvey and Gene Collins of Natural Resources are interested in establishing a Northern Ecological Marsh Interpretative Centre at Grace Lake.

(vi) Al Beck pointed out that presently the Lake does not have any special designation and there maybe a need, based on users, to look at Provincial planning and zoning issues.

(vii) John Towle clarified that integrity of the dykes is a maintenance matter and recommended a word change in the terms of reference. Grace Lake is a provincial waterway and is a Water Resources responsibility.

(viii) It was agreed that an additional term of reference should be added:

Present and Future Land Use Zoning should be reviewed.

(ix) Jim Lamontagne indicated that presently there is basically no industrial development in the Grace Lake area.

2. Establish Members of the Board

(i) It was agreed by all present that the following persons should be added to the Board.

Craig Hanley	-	Municipality Planning/Thompson
Bob Uchtmann	-	Marsh Manager/Department of Natural Resources/The Pas

(ii) It was also agreed that John Bodnar would be welcomed as an L.G.D. consultant who would represent the L.G.D. as they see fit.

(iii) It was also agreed that Murray Harvey should be contacted as a representative of "Friends of Grace Lake" to see if he would be interested in participating on this Board. Steve Davis would contact all the above noted people.

3. Review the parameters of the Grace Lake Study which is to be continued in 1990

(i) Al Beck gave an outline of the survey that the department of Environment intends to conduct on Grace Lake this spring, summer, and fall of 1990. The tests will cover a wide range

including bacteria, sediments for nutrients, chemistry and seasonal conditions. Literature and historical data will be reviewed and comparisons will be made to conditions in Montreal Lake.

(ii) Al Beck and Steve Davis will begin a first set of sampling on April 11, 1990 with 10 stations on Grace Lake and 5 stations on Montreal Lake.

(iii) Jim Lamontagne asked if the department would be recommending a course of action after all the test results are completed. Al Beck indicated that he would be making recommendations to the Board, based on the results. Al Beck also indicated that as the survey proceeds, the test results would be presented to the Board Members regularly at scheduled Board Meetings. He would prefer this rather than waiting for the completed report.

(iv) Jim Lamontagne requested that the next Board Meeting be scheduled after the sampling session, not before. This would allow some discussion as to any conditions noted at the time of sampling.

Items 4 and 5 of the agenda were briefly discussed and it was agreed that the Board would prepare the plan and recommendations taking into account all terms of reference and the lake sampling program.

This plan would then be brought to the people for further review and comment.

Next Meeting:

The next meeting would be held in the 2nd week of June. Participants will be notified as to the exact times and details.

MEETING WAS ADJOURNED AT 8:35 P.M.

APPENDIX IV (111)

GRACE LAKE WATER QUALITY MANAGEMENT BOARD - MINUTES -
MEETING - JUNE 19, 1990 - THE PAS

The meeting was convened at 7:15 P.M. with the following participants.

Steve Davis	-	Chairman/Department of Environment
Al Beck	-	Environment Officer/Department of Environment
Wendy Ralley	-	Environment Officer/Department of Environment
John Towle	-	Regional Water Manager/Water Resources
Jim Lamontagne	-	Councillor/Local Government District of Consol
Larry King	-	Councillor/Local Government District of Consol
Craig Hanley	-	Senior District Planner/Rural Development
Keith Lewis	-	Drafting Technician/Municipal Planning (assisting Craig Hanley)
Dennis Hlady	-	Natural Resource Officer/Department of Natural Resources (representing Bob Huck

1. Introduction

It was noted that Mr. John Fondse, Manager, Beaver Air will be attending future meetings as Reg Fast is no longer associated with Beaver Air Services. Both Bob Uchtmann and Nelson Fulford offered regrets prior to the meeting that they could not attend. Craig Hanley and Keith Lewis from Municipal Planning in Thompson were introduced. Dennis Hlady was filling in for Bob Huck. Wendy Ralley is the new Environment Officer with Water Standards and Studies in Winnipeg.

2. Review minutes of April 10, 1990 meeting - Al Beck moved that the minutes be adopted as presented. Seconded by Larry King. Motion was carried.

3. Administration

(i) John went through the report that he had prepared on the history of Grace Lake. John gave a detailed explanation as to how to read the water depth level markings. (Geodetic level of Grace Lake was 259.10).

(ii) Al Beck asked if Water Resources had any information on volumes of surface drainage to Grace Lake. John mentioned that the sewage lagoon is the primary source of water input into Grace Lake. Al Beck mentioned that this information would be necessary for future modelling as part of the study process. The modelling procedure would be set up to see if Grace Lake would improve if sewage discharge to Grace Lake was discontinued.

(iii) Seepage through the dyke on the east side of Grace Lake is still a problem for some residents. John Towle commented that the dykes are secure and not leaking. The source of water is local runoff. This contradicts dated information presented in John's report.

(iv) John noted the lagoon flow had a volume impact of only 0.19 ft. increase in Grace Lake level.

(v) Larry asked how much storm drain water goes through he sewage lagoon to Grace Lake? There seemed to be some difference of opinion as to how much storm sewer water actually goes through the sewage lagoon. This question would be pursued by S. Davis through Nelson Fulford. Al Beck mentioned that routing large volumes of storm water through sewage treatment facilities was an inefficient use of the sewage treatment system.

5. Al Beck's Report

Al Beck gave a presentation and handout of the data for the April 9, 1990 sampling of Grace Lake and Montreal Lake. A copy of this data/maps are attached. The following comments were highlighted:

(i) Montreal Lake was used as control lake because of similar characteristics to Grace Lake as it might have been originally.

(ii) Results give a clear indication that sewage effluent from the lagoon has a major impact on Grace Lake and is responsible for the extensive algae problem. This was not a surprise. The significant sewage related parameters were very high for Grace Lake and were low or normal for a natural lake like Montreal Lake. Al Beck specifically pointed out the following parameters as being of significance concerning sewage.

- Conductivity
- Sodium
- Potassium
- Total Nitrogen
- Total phosphorus
- Chloride
- Total Dissolved Phosphorus
- Fecal coliform bacteria

(iii) Total dissolved Phosphorus levels of 0.01 mg/l would be necessary to have a reduced aquatic weed problem. This parameter is related to the heavy algae bloom. Grace Lake has levels ranging from 2.70 - 0.09 mg/l. Montreal Lake ranged from 0.02 - 0.01 mg/l.

(iv) Ammonia

Levels of Ammonia at 0.05 mg/l would be a problem for fish life. Grace Lake levels range from 12.0 - 0.655 mg/l. Montreal Lake range from 0.05 - 0.13 mg/l.

(v) Al Beck mentioned that algae and aquatic weed growth are classic characteristics of sewage.

(vi) Larry asked why there was some deviation in results from some of the stations. Other than the distance factor from the sewage outfall, there was no particular reason at this time. Al reminded everyone that these results are not totally conclusive at this stage and further data would be necessary.

(vii) Al Beck mentioned that it was not widely accepted scientifically until 1974 that Total Dissolved Phosphorus was significant in sewage treatment. This of course was not considered in the 1973 CEC Licence of Grace Lake. At that time the impact of Total Dissolved Phosphorus levels were not known.

(viii) Jim Lamontagne asked if sampling Rall's Creek would be of any value? Al mentioned the results would be comparable to the results of G 10.

(ix) Al Beck also felt that Grace Lake would not revert to normal characteristics such as in Montreal Lake. Several reasons include: Grace Lake does not have any good water inflow patterns; it is not a deep lake and a vibrant plant growth has a good hold on the lake.

(x) Larry King reiterated that it is important to keep the Town involved in this process.

6. Review Terms of Reference

There was some concern raised about the wording of the Terms of Reference. Language changes were made to all 8 sections of the Terms of Reference. Craig Hanley moved to accept the changes as attached. The motion was seconded by Al Beck. The motion was carried. Please destroy old Terms of Reference. New one is attached.

7. Additional Items for Discussion

(i) S. Davis presented a letter and groundwater appraisal hazard from Mr. Austford regarding groundwater in the Grace Lake area. Copy of report is attached. It was also noted that some well monitoring on the east side of Grace Lake would be of value re: Terms of Reference.

(ii) John Towle asked if the L.G.D. have had any run-off or seepage problems this year. Jim Lamontagne answered that he was not aware of any particular problem in that area.

(iii) Craig Hanley indicated that he would review the contour lines and update land use in the Rall's Island Area.

(iv) The feasibility of re-routing a major water-way was discussed. This was not a feasible approach to a Grace Lake water flow problem.

8. Set Date Next Meeting

(i) It was agreed that the next Board Meeting would be in The Pas on September 6, 1990.

(ii) In the meantime an August and September sampling program would continue.

(iii) All Board Members would be advised.

MEETING WAS ADJOURNED AT 8:45 P.M.

APPENDIX IV (iii)

GRACE LAKE WATER QUALITY MANAGEMENT BOARD - MINUTES - SEPTEMBER 6, 1990 - MEETING - THE PAS

The meeting was convened at 1:00 P.M. with the following participants. The agenda was distributed.

Steve Davis	-	Chairman/Department Environment
Al Beck	-	Environment Officer/Department of Environment
Wendy Ralley	-	Environment Officer/Department of Environment
John Towle	-	Regional Water Management/Water Resources
John Fondse	-	Manager/Beaver Air Service - Grace Lake
Bob Uchtmann	-	Marsh Manager/Department of Natural REsources
Nelson Fulford	-	Municipal Superintendent/Town of The Pas

1. The Minutes of the June 19, 1990 Meeting were discussed.

Nelson Fulford was asked about storm sewer discharge. There were no storm drains that discharge to the sewage lagoon. However, Nelson pointed out that "bleeders" in the winter time account for a considerable increase in water use and subsequent sewage volumes increase. He also noted that weeping tiles from homes are tied into the sewer system.

2. Al Beck's Report

Al Beck distributed copies of the following reports:

(i) Results from the June 19, 1990 sampling period for Grace Lake (10) stations). An average value has been added for the results for each parameter.

(ii) Results for the June 19, 1990 sampling period for Montreal Lake. Two stations have been added to replace the original 5 for this month only. Mean values have been added for the results for each parameter.

(iii) Chlorophyll levels have been added to all the analytical reports including the April 11, 1990 set of samples.

(iv) Fecal Coliform and Total Coliform results have been recorded. These reports are attached for reference.

(v) Comments/Observations

Water chemistry results of the previous sampling periods are consistent with previous readings. There is no doubt that sewage discharge is the cause of the algae proliferations. It is very rare to see such "clear cut results".

Total and fecal Coliform Bacteria levels are within the acceptable levels and are within water contact guidelines.

Bob Uchtmann asked what do the results show concerning human health and safety? There is a certain unpleasantness with no direct human impact. However, there are some species of algae that would be harmful to animals if Grace Lake water was used as a sole source of water supply.

It was noted that "Chlorophyll a" was higher in Montreal Lake than Grace Lake because the nutrients are taken up by the weed population which is much higher in Grace Lake. This will change with the advancement of summer months. Chlorophyll results are portional in that the higher the algae counts, the higher the chlorophyll results.

A full set of samples were taken September 5 - 6, 1990.

Al wants to take 30 - 40 cm bottom core samples from the lake bottom. This will show the profile of nutrients and nutrient supply to the lake. This will be done on the next sampling period.

S. Davis asked what would be the effects on Grace Lake if lagoon flow was stopped? John Towle indicated that the lake level would drop 3" and total surface area of the lake would decline. Water levels would drop to 1960's levels and dry years would be a problem for the Air Service.

S. Davis asked about the oxygen level scenario with no flow in Grace lake? Al mentioned that the lake is almost anoxic in winter anyway, but there would be a decrease in oxygen.

John Towle mentioned that the drainage basin around Grace Lake is very small (4 sq. miles).

Al Beck mentioned that phosphorous could be reduced by treatment at the sewage lagoon prior to discharge.

3. New Business

(i) Memo from Craig Hanley to John Towle regarding watershed contour information - memo attached.

(ii) S. Davis indicated in referring back to the terms of reference that this office has water analysis data from 70 wells in the Grace Lake area. It was agreed that Steve would plot these results on a map. In general iron, hardness appears to be elevated in the area. These parameters are of no particular public health concern.

(iii) Al Beck asked the Board for an endorsement of the Department of Environment's position regarding further development of subdivisions in the Town of The Pas. He proposed the following motion which was seconded by John Towle and was unanimously carried. Motion attached.

Discussion on motion - Nelson Fulford mentioned that the flow limits (hydraulic loading) are already exceeded, but all parameters in the CEC licence are presently being met.

(iv) S. Davis would prepare a basic outline for the Board's report for discussion at the next meeting.

(v) John Towle read an old news article dealing with misleading information about Grace Lake water quality. He was concerned that we should be providing more accurate data and publicity on the Board's activity. It was agreed that a letter to the editor from the Board would be appropriate. S. Davis and A. Beck would follow upon this this.

(vi) Nelson Fulford also mentioned that sewage from private sewage systems in the L.G.D. is discharged into the lagoon from pump out vehicles.

4. Next Meeting

It was agreed that the next meeting we would begin to address -

(i) Report Outline

(ii) Schedule of reports

(iii) Content

The next Board Meeting would be November 29, 1990 at 1:00 P.M. at The Pas. This will be confirmed.

MOVED THAT:

The Grace Lake Management Board endorse the Manitoba Environment position that:

1) Development of subdivisions not proceed until a review of the sewage treatment facility capacity can be completed;

AND THAT:

2) Such development subsequently be approved only if the additional wastes to be generated from the subdivisions can be accommodated by the sewage treatment facility without exceeding the CEC Licence limits for those parameters to including hydraulic loading rates.

APPENDIX IV (iv)

GRACE LAKE WATER QUALITY MANAGEMENT BOARD - MINUTES - MEETING - NOVEMBER 29, 1990

1. The meeting was convened at 1:00 P.M. by Chairman Steve Davis with the following participants:

Steve Davis	-	Chairman/Department of Environment
Al Beck	-	Environment Officer/Department of Environment
Wendy Ralley	-	Environment Officer/Department of Environment
Jim Lamontagne	-	Councillor/Local Government District of Consol
Larry King	-	Councillor/Local Government district of consol
Nelson Fulford	-	Municipal Superintendent/Town of The Pas

2. The agenda was distributed.

3. Minutes of the September 6, 1990 meeting were reviewed and discussed. There were several clarifications that arose from the minutes.

   (i) Jim Lamontagne questioned the toxicity of algae. He mentioned that Mr. A. Rahl on Rall's Island waters his livestock for a period during the summer from Grace Lake. Steve Davis mentioned that he would get some algae and toxicity material together and write to Mr. Rahl regarding the danger posed by this practice. Al Beck mentioned that there are types of blue-green algae that produce toxins at various times that would be toxic to livestock.

   (ii) Jim Lamontagne requested a clarification regarding the "hydraulic loading" term used in reference to the Sewage Lagoon.

   (iii) Al Beck mentioned that the bottom core samples could not be taken due to the 20 cm or so of loose organic material on the bottom of the Lake. It is not a sufficiently solid bottom to permit accurate core sampling.

   (iv) There was discussion regarding dissolved oxygen. Al mentioned one reason why 0_2 concentration was so low in winter was due to 0_2 consumption by the decomposed algae. Ice cover was another reason.

   (v) Larry King asked if Nelson had any volume figures regarding sewage received from the L.G.D.'s private sewage disposal systems. There was a rough guesstimate of about 12,000 gals. per year based on 125 families x 1 pump out per year.

   (vi) Jim Lamontagne inquired whether the subdivision development freeze on the Town of The Pas extended to the L.G.D.? Steve Davis advised that it did not.

4. Motion by Nelson Fulford and seconded by Al Beck that the minutes be adopted. All members were in favor.

5. Data Collection - Agenda Item 2 - Al Beck's Report

(i) Copies of data sheets for all sample locations were distributed. The September 6, 1990 set of samples for both Grace Lake and Montreal Lake were added. This data is attached to the minutes.

(ii) Al Beck mentioned there were no changes in bacteria levels which was probably due to chlorination of lagoon effluent and holding contact time. There is no evidence of a bacteria problem in Grace Lake.

(iii) Al Beck gave us a chemistry lesson regarding ammonia removal by adding oxygen to produce nitrate. Fish populations cannot tolerate ammonia but can tolerate nitrate.

(iv) Steve asked about the difference between Total Phosphorous and Total Dissolved Phosphorous. Total Phosphorous is a measure of all the various Phosphorous whereas total Dissolved is one portion of the Total Phosphorous. Generally, the Total Dissolved Phosphorous is about 10% of total. This is not the case in this instance; rather it is 90%. This is probably due to loading from the sewage lagoon.

(v) The increase in turbidity in July was mainly due to algae in Grace Lake. These levels were not found in Montreal Lake.

(vi) S. Davis asked what additional sampling would be left to done. Al Beck mentioned that it was necessary to evaluate the total phosphorous in sediment. Al mentioned that the last set of samples taken in November would be the last set done.

(vii) Al Beck mentioned that many of the variables in the data tables are not a direct indication of what is discharged into the lake but rather are secondary indicators of the biological reactions taking place. Example; iron and manganese increase as O_2 decreases.

(viii) Jim Lamontagne asked if there was a reduction of Phosphorous from the lagoon effluent; would the Phosphorous levels in the lake be reduced. Al mentioned that, due to the supply in the sediments and the tremendous amounts of phosphorous stored in plants in the lake, if the loading stopped, it would take many years to reduce the euthrophication process.

(ix) Jim Lamontagne asked if the Board has heard from Murray Harvey regarding the status of the "Friends of Grace Lake". Steve Davis said he had not heard from this group, but noted that all minutes and notices of meetings had been sent to them.

6. Rall's Island Map - Domestic Wells Posted

(i) Steve Davis prepared a map of Rall's Island and plotted 57 domestic wells on the map and attached all the individual chemical analysis results. Majority of the wells are at the 100' level. The Town of The Pas auxiliary fire wells are at 190'. These latter are very high in sodium and chlorides. Larry mentioned that this was consistent with deep aquifer wells in the Carrot Valley and Western Canada.

(ii) Steve Davis mentioned that he could see no apparent correlation between the Saskatchewan River,, Town Auxiliary wells and Grace Lake affecting the 100' level aquifer on Rall's Island. Al Beck mentioned that he will take it back to Winnipeg and have Department groundwater hydrologists review the data.

7. Board Report and Recommendations

(i) Al Beck distributed an outline for the draft report. This outline is attached to the minutes. This outline would address 4 of the 7 Terms of Reference. There was a discussion of each item in the outline. The group felt that the outline was excellent.

(ii) Nelson Fulford recommended that the report be written to include both the technical aspect but written in such a way as to be meaningful to the lay people or the general public. This was agreed and was certainly one of the goals of this group.

(iii) Nelson Fulford mentioned that the Board should be prepared for the eventuality that there may be no changes necessary to Grace Lake. Jim Lamontagne mentioned that he hoped we would all be open mined about the issues.

(iv) Steve Davis indicated to be consistent, we should try to use the 7 headings in Al's outline in the other 3 Terms of Reference where possible.

8. Schedule of Report

(i) First Draft date was tentatively for March 1991.

(ii) Nelson is sending out raw data to his consultant to be used in their engineering review of the Town Sewage Lagoon. The Board has no objections to this and welcomed the opportunity for the data to be used.

(iii) Al mentioned he would try and get the draft report out before the meeting in March 1991.

9. New Business

(i) Jim Lamontagne was concerned regarding the length of time between now and draft report. As a result it was decided that the Board would meet in mid January 1991 to discuss outline for the other 3 Terms of reference not addressed in the Technical data outline. These 3 include:

1. Examine the implication of increased resource use.

2. Review criteria for lake level management and dyke maintenance.

3. Present and Future Land Use Zoning.

(ii) Also it was suggested that S. Davis provide a small article to the newspaper informing the public that a draft report will be ready in March 1991.

(iii) S. Davis would contact both Craig Hanley and John Towle to request that they prepare an outline for the January meeting for discussion on the Terms of Reference items below.

Craig Hanley - Term of Reference #7

John Towle - Term of Reference #3

(iv) S. Davis will be sending out exact dates of the January and March 1991 meetings.

MEETING WAS ADJOURNED AT 3:30 P.M.

APPENDIX IV (v):

GRACE LAKE WATER QUALITY MANAGEMENT BOARD - MEETING - MINUTES - JANUARY 29, 1991

1. The meeting was convened at 1:00 P.M. by Chairman Steve Davis with the following participants:

Steve Davis	-	Chairman/Department of Environment
Craig Hanley	-	Senior District Planner/Rural Development
John Towle	-	Regional Water Manager/Water Resources
Gary Ceppetelli	-	Planner/Rural Development (assisting Craig Hanley)
Larry King	-	Councillor/Local Government District of Consol
Jim Lamontagne	-	Councillor/Local Government District of Consol
Bruce Palechaty	-	Natural Resource Officer/Department of Natural Resources (representing Bob Huck)

2. The minutes of the November 29, 1990 were reviewed and discussed. There were several clarifications that arose from the minutes.

   (a) Craig Hanley requested a clarification on item 3 (vi) of the previous minutes. Steve Davis explained that the questions arose as part of the discussion regarding the present use of the Town Sewage Lagoon receiving sewage from the L.G.D. via pump out truck. As a result of concerns associated with continued subdivision development in The Pas, the Department of Environment has curbed present development. This would have no impact on the L.G.D. developemnts.

   (b) S. Davis indicated that he is presently gathering information on Algae to give to Mr. A. Rahl who apparently waters some of his livestock on Grace Lake. This is not a good practice. S. Davis will follow-up on this concern.

   (c) S. Davis indicated that CBC Thompson had contacted him about 2 weeks ago regarding the status of the Board's report.

3. A motion was made by Craig Hanley and seconded by Larry King that the minutes be adopted. All members were in favor.

4. Agenda items 2 and 3 would be deferred as Al Beck and Wendy Ralley were unable to attend the meeting. In speaking with Al Beck on January 29, 1991, he indicated that the draft report that he is presently working on is coming along on schedule. Al also mentioned the November laboratory results had not yet been received/evaluated.

5. **Report Outline - Term of Reference - Craig Hanley -**

   (a) Craig submitted a basic outline concerning Term of Reference No. 7 dealing with Rahl's Island Zoning (present and future). This outline is attached.

   (b) Craig will be putting together a reduced scale map which will have all the pertinent information included for all the Rahl's Island area including the area adjacent to Grace lake. It was interesting to note from Craig that 60% of the land mass on Rahl's Island is Crown Land.

   (c) Craig will forward his report to Al Beck.

6. **Report Outline - Term of Reference #3 - John Towle**

   (a) John indicated that the previously submitted Water Level Management Report is still applicable and relevant for our purposes. He indicated that the 5 recommendations could be pulled out of the report to reflect our Board Term of Reference #3. This was quite acceptable to the Board.

   (b) John mentioned that due to the dry years, no water management of Grace Lake had been necessary since spring 1986. Management level is 260.06 M. Due to these dry years, the first step outlined in the report in minimizing seepage has not been necessary to implement and as such the report has not had the opportunity or necessity of being implemented.

   (c) John also indicated that water levels for 1990 were basically the same as 1988.

   (d) John reviewed Figure 2 (water level chart) indicating that (non-metric) 1 big square on the chart was approximately 20" of water and one small square was 2' of water.

   (e) John indicated that there still is below average snow fall in this area and he does not antcipate any appreciable run-off to Grace lake this year. John provided on interesting precipitation map for last year (April - October) which shows this area as having 53% of normal precipitation and the distinction of being the driest area in Manitoba.

7. **Discussion - Strategies - Report**

(a) Craig suggested that an Executive Summary be developed for the report. Larry also indicated that this would be one good way of getting the basic factual information out to concerned groups on a larger scale rather than providing the full report to everyone. We would pursue this approach and felt it was a good idea.

(b) Craig also suggested that the report provide a "contact person" along with telephone numbers in order that people can get more information.

(c) A question arose as to how many full reports would have to be printed. A bare minimum of 25 appeared to be a good figure. Possible numbers were:

Town of The Pas	- 5
L.G.D.	- 5
Board	- 10
Press	- 2
Government	- 3

(d) S. Davis indicated that the costs of the report would be discussed with Al Beck.

(e) John suggested that the monthly water level chart would be condensed for the report. Also Bruce Webb has the master plates for the pictures which are in the Water Level Management Report if we need them.

f) Also, it was discussed that a public meeting may be necessary once the report is completed. This would likely be done through the L.G.D. Council. This issue regarding exact course of action following completion of the report will be further explored as to what is the most effective way to get the information to the public. It was noted that this was one of our objectives at the outset and will remain an important part of the process.

8. **New Business**

New items were not discussed. Attached for background information is a letter written by Al Beck in 1989 concerning odor, taste, and water quality problems associated with a lake from algae growth in Southern Manitoba. This letter contains some interesting parallels to Grace Lake and to some of the concerns expressed by the public.

9. **Next Meeting**

It was suggested that April 9, 1991 would be an appropriate date for the next meeting. This will be confirmed and all members will be advised.

Meeting was adjourned at 3:00 P.M.

GRACE LAKE WATER CHEMISTRY,
APRIL 11, 1990

Sampling Site	G-1	G-2	G-3	G-4	G-5	G-6	G-7	G-8	G-9	G-10
Conductivity (uS /cm)	719	758	1040	1130	1250	872	653	514	1040	359
pH (units)	7.20	7.33	7.44	7.58	7.63	7.70	7.71	7.74	7.65	8.17
Alkalinity (CaCO3 mg/L)	214	250	381	448	498	327	239	182	406	116
Alkalinity (HCO3 mg/L)	261	307	465	547	608	399	292	222	495	142
Alkalinity (CO3 mg/L)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alkalinity (OH mg/L)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Calcium (mg/L)	48.9	50.3	67.2	73.3	74	47.5	38.6	29.9	65.3	16.1
Magnesium (mg/L)	24.6	31.6	49.0	62.0	62.8	43.7	36.0	28.3	57.1	20.0
Hardness (mg/L)	224	256	370	438	443	299	245	191	399	123
Sodium (mg/L)	46.5	48.4	65.3	71.4	73.5	51.3	42.0	33.5	65.3	24.0
Potassium (mg/L)	7.0	7.5	10.0	10.5	11.0	7.5	5.5	5.0	9.0	L5.0
Iron (mg/L)	0.26	0.69	1.46	1.44	1.44	1.02	1.01	0.53	1.11	0.28
Manganese (mg/L)	0.04	0.26	0.64	0.97	1.14	0.74	0.61	0.47	0.97	0.15
Dissolved Oxygen (mg/L)	5.4	0.5	2.3	2.9	3.6	3.6	3.9	5.3	2.4	5.0
Colour (TCU)	G50	40	G50	40	40	20	G25	L20	L35	L10
Turbidity (NTU)	0.84	2.4	2.7	5.2	3.0	4.0	4.6	1.17	3.1	2.0
Total Nitrogen (mg/L)	13.50	11.50	10.00	7.05	6.35	4.00	2.85	2.35	3.80	1.95
Ammonia (mg/L)	12.0	9.35	7.85	4.05	3.55	2.05	1.3	0.99	1.8	0.655
Dissolved Nitrogen (mg/L)	0.20	0.04	0.02	0.08	0.74	0.18	0.18	0.32	0.19	0.36
Total Phosphorus (mg/L)	2.90	2.60	2.42	1.40	1.04	0.83	0.50	0.83	0.49	0.53
Total Dissolved Phosphorus (mg/L)	2.70	2.45	2.00	0.470	0.260	0.130	0.120	0.090	0.110	0.110
Chloride (mg/L)	53	57	80	90	98	70	48	40	73	25
Sulphate (mg/L)	72	62	65	52	76	42	38	25	38	25
Silicon Dioxide (mg/L)	6.1	11.9	24.8	34.9	37.9	24.8	16.6	13.3	28.8	8.2
Total Depth (M)	0.37	1.10	1.81	2.00	1.84	2.00	1.99	1.96	2.01	1.71
Secchi Depth (M)	0.37	0.66	0.58	0.59	0.53	0.82	0.82	1.25	0.69	1.44
Fecal Coliform (No. /100 mL)	9	15	1100	0	0	0	0	0	0	0
Total Coliform (No. /100 mL)	93	15	G1500	4	0	0	0	0	0	0
Chlorphyll - a (ug/L)	L1.00	L1.00	L1.00	7.49	4.99	4.66	3.0	8.99	4.0	8.16

G - Greater Than
L - Lesser Than
mg/L - milligrams per Litre
M - Meter

Conductivity - uS/cm are equivalent units to umho/cm.

APPENDIX V (1b)

MONTREAL LAKE WATER CHEMISTRY, APRIL 11, 1990

Sampling Site	M-1	M-2	M-3	M-4	M-5
Conductivity (uS /cm)	257	308	176	289	278
pH (units)	7.17	7.55	7.46	7.45	7.72
Alkalinity (CaCO3 mg/L)	123	152	82.9	141	133
Alkalinity (HCO3 mg/L)	150	185	101	172	162
Alkalinity (CO3 mg/L)	0.0	0.0	0.0	0.0	0.0
Alkalinity (OH mg/L)	0.0	0.0	0.0	0.0	0.0
Calcium (mg/L)	26.5	33.5	18.9	32.5	27.9
Magnesium (mg/L)	17.9	21.7	11.8	19.3	18.6
Hardness (mg/L)	140	173	96.5	161	146
Sodium (mg/L)	4.70	5.00	3.19	4.52	4.50
Potassium (mg/L)	L5.0	L5.0	L5.0	L5.0	L5.0
Iron (mg/L)	0.67	2.70	3.90	L0.01	L0.01
Manganese (mg/L)	0.36	0.49	0.027	0.02	0.02
Dissolved Oxygen (mg/L)	1.3	8.6	6.6	.	.
Colour (TCU)	G50	L30	10	20	20
Turbidity (NTU)	2.7	6.6	7.4	7.8	4.2
Total Nitrogen (mg/L)	1.25	1.65	1.55	2.95	1.35
Ammonia (mg/L)	0.050	0.130	0.070	0.050	0.330
Dissolved Nitogen (mg/L)	0.08	0.14	0.06	0.05	0.05
Total Phosphorus (mg/L)	0.055	0.100	0.165	0.280	0.060
Chloride (mg/L)	1.65	1.40	0.90	1.25	1.30
Sulphate (mg/L)	25	20	20	12	18
Silicon Dioxide (mg/L)	6.0	7.0	3.5	5.6	4.8
Total Dissolved Phosphorus (mg	0.020	L0.010	0.010	0.010	L0.010
Total Depth (M)	1.62	0.75	2.31	2.28	2.33
Secchi Depth (M)	0.91	0.75	0.39	.	0.48
Fecal Coliform (No. /100 mL)	0	0	0	0	0
Total Coliform (No. /100 mL)	0	0	0	0	0
Chlorphyll - a (ug/L)	3	30	50.11	61.76	12.49

G - Greater Than
L - Lesser Than
mg/L - milligrams per Litre
M - Meter
. - represents missing data

Conductivity - uS/cm are equivalent units to umho/cm.

GRACE LAKE WATER CHEMISTRY,
JUNE 19, 1990

Sampling Site	G-1	G-2	G-3	G-4	G-5	G-6	G-7	G-8	G-9	G-10
Conductivity (uS /cm)	723	553	557	553	557	558	560	559	556	555
pH (units)	7.67	8.80	8.64	8.73	8.69	8.68	8.63	8.63	8.72	8.59
Alkalinity (CaCO3 mg/L)	259	219	219	218	219	218	218	219	218	219
Alkalinity (HCO3 mg/L)	316	221	234	230	229	233	232	236	229	224
Alkalinity (CO3 mg/L)	0.0	22.3	16.1	18.1	18.7	16.4	16.8	15.4	18.5	11.4
Alkalinity (OH mg/L)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Calcium (mg/L)	49.8	36.0	35.8	36.2	34.0	36.2	35.7	35.6	36.0	34.0
Magnesium (mg/L)	40.0	36.0	33.6	33.0	32.1	33.8	32.9	33.1	33.5	32.8
Hardness (mg/L)	290	238	227	227	217	230	224	226	228	220
Sodium (mg/L)	43.8	39.7	39.2	39.7	38.5	40.2	39.8	39.3	39.6	38.3
Potassium (mg/L)	6.0	5.5	5.5	5.5	5.5	7.0	5.5	5.5	L5.0	5.0
Iron (mg/L)	0.15	0.14	0.27	0.36	0.63	0.21	0.19	0.18	0.18	0.15
Manganese (mg/L)	0.04	L0.02	0.02	0.03	0.02	0.03	0.03	0.03	0.04	0.04
Dissolved Oxygen (mg/L)	1.4	10.6	9.3	10.4	9.7	9.8	9.0	9.5	9.7	9.3
Colour (TCU)	G50	20	20	20	20	20	20	20	20	20
Turbidity (NTU)	1.28	1.62	5.1	3.2	2.5	1.86	2.0	2.3	2.2	2.2
Total Nitrogen (mg/L)	7.15	1.55	1.70	1.60	1.50	1.55	1.65	1.55	1.70	1.55
Ammonia (mg/L)	6.100	0.110	0.115	0.026	0.032	0.043	0.055	0.060	0.050	0.090
Dissolved Nitogen (mg/L)	0.02	0.03	0.04	0.01	0.02	0.02	0.04	0.03	0.02	0.04
Total Phosphorus (mg/L)	2.25	0.370	1.55	0.375	0.335	0.360	0.365	0.375	0.400	0.360
Total Dissolved Phosphorus (mg.L)	2.25	0.330	0.260	0.300	0.300	0.315	0.300	0.315	0.310	0.300
Chloride (mg/L)	55	43	43	43	43	43	43	43	43	43
Sulphate (mg/L)	50	28	25	25	25	25	25	25	25	22
Silicon Dioxide (mg/L)	5.4	6.4	7.3	8.1	7.8	7.8	7.6	7.7	7.7	7.7
Total Depth (M)										
Secchi Depth (M)	0.84	1.19	1.7	1.18	1.36	1.49	1.35	1.41	1.52	1.43
Fecal Coliform (No. /100 ml.)	4	0	0	0	4	0	14	7	0	0
Total Coliform (No. /100 ml.)	39	0	0	0	4	4	14	14	0	0
Chlorphyll - a (ug/L)	L0.01	2.00	17.48	9.99	8.49	6.99	8.49	4.49	4.99	5.49

G - Greater Than
L - Lesser Than
mg/L - milligrams per Litre
M - Meters

Conductivity - uS/cm are equivalent units to umho/cm.

APPENDIX V (iib)

MONTREAL LAKE WATER CHEMISTRY, JUNE 19, 1990

	M-6	M-7
Conductivity (uS /cm)	226	232
pH (units)	8.42	7.93
Alkalinity (CaCO3 mg/L)	117	119
Alkalinity (HCO3 mg/L)	130	145
Alkalinity (CO3 mg/L)	6.16	0.0
Alkalinity (OH mg/L)	0.0	0.0
Calcium (mg/L)	26	25.2
Magnesium (mg/L)	16.5	17.4
Hardness (mg/L)	133	135
Sodium (mg/L)	3.52	3.45
Potassium (mg/L)	L5.0	L50
Iron (mg/L)	0.31	0.73
Manganese (mg/L)	0.09	0.13
Dissolved Oxygen (mg/L)	.	.
Colour (TCU)	25	40
Turbidity (NTU)	2.0	2.2
Total Nitrogen (mg/L)	0.950	1.050
Ammonia (mg/L)	0.011	0.020
Dissolved Nitrogen (mg/L)	L0.01	L0.01
Total Phosphorus (mg/L)	0.052	0.044
Chloride (mg/L)	0.75	0.7
Sulphate (mg/L)	2.70	2.55
Silicon Dioxide (mg/L)	1.2	1.0
Total Dissolved Phosphorus (mg	0.015	0.020
Total Depth (M)		
Secchi Depth (M)		
Fecal Coliform (No. /100 mL)	4	0
Total Coliform (No. /100 mL)	4	0
Chlorophyll - a (ug/L)	5.49	16.48

G - Greater Than
L - Lesser Than
mg/L - milligrams per Litre
M - Meter

Conductivity - uS/cm are equivalent units to umho/cm.

GRACE LAKE WATER CHEMISTRY,
JULY 31, 1990

Sampling Site	G-1	G-2	G-3	G-4	G-5	G-6	G-7	G-8	G-9	G-10
Conductivity (uS /cm)	580	592	587	583	583	579	587	585	583	578
pH (units)	9.47	9.18	9.15	9.19	9.20	9.30	9.17	9.24	9.24	9.26
Alkalinity (CaCO3 mg/L)	242	241	240	240	242	243	242	242	243	245
Alkalinity (HCO3 mg/L)	167	209	213	209	209	193	215	203	204	205
Alkalinity (CO3 mg/L)	62.7	41.7	39.5	41.3	42.3	50.6	39.8	0.0	45.8	46.0
Alkalinity (OH mg/L)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Calcium (mg/L)	36.8	37.5	37.5	38.2	40	38.8	37.5	37.8	37.5	36.8
Magnesium (mg/L)	34.7	34.9	34.9	34.9	35.9	35.2	34.0	34.8	34.5	33.2
Hardness (mg CaCO3/L)	235	238	238	240	248	242	235	238	236	229
Sodium (mg/L)	40.6	40.1	40.1	39.8	39.8	39.0	39.0	39.0	39.8	38.0
Potassium (mg/L)	6.5	6.5	6.5	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Iron (mg/L)	0.22	0.46	0.59	0.87	1.09	0.98	0.99	0.77	0.89	1.20
Manganese (mg/L)	0.03	0.03	0.04	0.05	0.06	0.07	0.07	0.06	0.06	0.08
Dissolved Oxygen (mg/L)	11.5	8.4	8.2	9.5	10	9.5	9.4	9.3	7.9	9.0
Colour (TCU)	G40 L50	G40 L50	35	G35 L40	G40 L50	G35 L40	40	G25 L30	G25 L30	G35 L40
Turbidity (NTU)	5.8	14	17	20	23	17	27	22	23	29
Total Nitrogen (mg/L)	2.55	2.95	2.90	2.65	2.90	2.90	2.80	3.10	2.85	2.75
Ammonia (mg/L)	0.084	0.365	0.375	0.220	0.078	0.031	0.175	0.115	0.230	0.057
Dissolved Nitogen (mg/L)	0.15	0.16	0.12	0.08	0.10	0.06	0.10	0.09	0.05	0.04
Total Phosphorus (mg/L)	0.540	0.600	0.525	0.570	0.590	0.580	0.585	0.600	0.520	0.630
Total Dissolved Phosphorus (mg.L)	0.445	0.480	0.415	0.45	0.373	0.380	0.380	0.400	0.365	0.365
Chloride (mg/L)	50	48	48	48	48	48	48	48	48	48
Sulphate (mg/L)	18	18	18	18	18	18	18	18	15	15
Silicon Dioxide (mg/L)	10.0	9.9	10.1	10.1	9.9	10.1	10.1	10.1	10.1	10.1
Total Depth (M)										
Secchi Depth (M)	0.60	0.49	0.43	0.32	0.28	0.29	0.28	0.35	0.31	0.31
Fecal Coliform (MPN)	0	4	0	0	4	0	0	0	0	0
Total Coliform (MPN)	0	23	4	0	4	0	0	4	0	4
Chlorphyll - a (ug/L)	36.7	42	50.7	87.4	96.1	85.6	78.7	71.7	50.7	108

G - Greater Than
L - Lesser Than
mg/L - milligrams per Litre
M - Meter
MPN - Most Probable Number

Conductivity - uS/cm are equivalent units to umho/cm.

APPENDIX V (iii b)

MONTREAL LAKE WATER CHEMISTRY
JULY 31, 1990

Sampling Site	M-1	M-2	M-3	M-4	M-5
Conductivity (uS /cm)	234	234	234	229	225
pH (units)	8.68	8.61	8.65	8.92	9.16
Alkalinity (CaCO3 mg/L)	122	122	122	121	121
Alkalinity (HCO3 mg/L)	130	133	131	119	108
Alkalinity (CO3 mg/L)	8.95	7.97	8.84	14.2	19.8
Alkalinity (OH mg/L)	0.0	0.0	0.0	0.0	0.0
Calcium (mg/L)	25.0	26.3	25.2	24.9	23.8
Magnesium (mg/L)	16.2	16.9	16.8	16.3	16.1
Hardness (mg/L)	130	136	133	129	126
Sodium (mg/L)	3.43	3.48	3.53	3.40	3.40
Potassium (mg/L)	L5.0	L5.0	L5.0	L5.0	L5.0
Iron (mg/L)	0.29	0.47	0.49	0.47	0.4
Manganese (mg/L)	0.11	0.17	0.16	0.13	0.13
Dissolved Oxygen (mg/L)	9.5	8.8	8.7	8.6	9.3
Colour (TCU)	G25 L30	G25 L30	G25 L30	20	G25 L30
Turbidity (NTU)	5	3.3	5.1	4.7	4.4
Total Nitrogen (mg/L)	1.20	1.35	1.35	1.45	1.20
Ammonia (mg/L)	0.006	0.009	0.009	0.008	0.007
Dissolved Nitogen (mg/L)	L0.01	L0.01	L0.01	L0.01	L0.01
Total Phosphorus (mg/L)	0.046	0.059	0.066	0.061	0.053
Chloride (mg/L)	0.90	0.90	0.90	0.90	0.80
Sulphate (mg/L)	1.75	3.20	3.00	2.80	18.00
Silicon Dioxide (mg/L)	3.5	3.9	3.9	4.0	3.5
Total Dissolved Phosphorus (mg.L)	0.012	0.012	0.012	0.012	0.012
Total Depth (M)					
Secchi Depth (M)					
Fecal Coliform (No. /100 mL)	0	0	0	0	4
Total Coliform (No. /100 mL)	4	9	23	7	9
Chlorphyll - a (ug/L)	11.4	21.0	22.7	23.6	15.7

G - Greater Than
L - Lesser Than
mg/L - milligrams per Litre
M - Meter

Conductivity - uS/cm are equivalent units to umho/cm.

GRACE LAKE WATER QUALITY,
SEPTEMBER 6, 1990

Sampling Site	G-1	G-2	G-3	G-4	G-5	G-6	G-7	G-8	G-9	G-10
Conductivity (uS /cm)	705	641	600	603	618	600	606	602	602	604
pH (units)	8.22	8.90	9.42	9.41	9.20	9.42	9.38	9.45	9.43	9.42
Alkalinity (CaCO3 mg/L)	267	258	257	257	257	2.53	257	256	256	256
Alkalinity (HCO3 mg/L)	326	243	175	182	211	174	184	171	176	178
Alkalinity (CO3 mg/L)	0.0	35.3	68.0	64.9	50.7	66.1	63.5	69.3	66.9	65.7
Alkalinity (OH mg/L)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Calcium (mg/L)	43.1	42.4	46.1	43.6	44.6	42.4	41.1	41.6	40.7	40.8
Magnesium (mg/L)	37.5	40.0	40.0	39.5	40.3	39.2	39.0	39.1	38.3	38.5
Hardness (mg CaCO3/L)	262	271	280	271	277	267	262	265	260	262
Sodium (mg/L)	48.0	47.1	48.3	47.6	47.0	46.5	45.5	46.6	45.9	46.0
Potassium (mg/L)	7.5	7.5	7.5	8.0	8.0	8.0	7.5	7.5	7.5	7.0
Iron (mg/L)	0.11	0.25	1.37	1.30	1.37	0.83	0.49	0.41	0.39	0.35
Manganese (mg/L)	0.05	0.25	0.09	0.09	0.11	0.07	0.05	0.04	0.04	0.04
Dissolved Oxygen (mg/L)	1.6	3.2	8.0	8.2	6.5	7.5	7.9	9.0	8.6	8.1
Colour (TCU)	40	G35 L40	40	40	40	G40 L50	G40 L50	G40 L50	40	G40 L50
Turbidity (NTU)	1.04	4.9	28	23	28	17	11	7.3	6.0	6.7
Total Nitrogen (mg/L)	6.95	4.30	4.50	4.70	4.85	4.50	6.25	4.70	4.30	4.70
Ammonia (mg/L)	4.82	1.39	0.955	0.915	0.995	1.16	1.16	0.905	0.755	0.985
Dissolved Nitogen (mg/L)	0.03	0.18	0.04	L 0.01	0.06	L0.01	0.01	L0.01	0.01	L0.01
Total Phosphorus (mg/L)	1.27	0.98	0.88	0.88	0.88	0.78	0.83	0.83	0.83	0.83
Total Dissolved Phosphorus (mg.L)	1.13	0.88	0.66	0.65	0.7	0.64	0.61	0.64	0.62	0.62
Chloride (mg/L)	55	53	53	53	53	53	53	53	53	53
Sulphate (mg/L)	32	20	18	18	18	18	18	18	18	20
Silicon Dioxide (mg/L)	13.1	13.3	12.4	12.6	13.2	12.4	12.4	12.6	12.6	12.6
Total Depth (M)										
Secchi Depth (M)	0.61	0.52	0.29	0.28	0.3	0.35	0.42	0.52	0.52	0.48
Fecal Coliform (No. /100 mL)	0	4	0	0	0	4	0	0	0	4
Total Coliform (No. /100 mL)	23	4	0	0	0	4	0	0	0	4
Chlorphyll - a (ug/L)										

G - Greater Than
L - Lesser Than
mg/L - milligrams per Litre
M - Meter

Conductivity - uS/cm are equivalent units to umho/cm.

APPENDIX V (iv b)

MONTREAL LAKE WATER QUALITY
SEPTEMBER 6, 1990

Sampling Site	M-1	M-2	M-3	M-4	M-5
Conductivity (uS /cm)	241	237	233	231	226
pH (units)	8.78	8.96	9.01	9.05	9.24
Alkalinity (CaCO3 mg/L)	126	123	124	122	121
Alkalinity (HCO3 mg/L)	112	91.3	103	95.8	74.9
Alkalinity (CO3 mg/L)	20.5	28.9	23.8	26.3	35.8
Alkalinity (OH mg/L)	0.0	0.0	0.0	0.0	0.0
Calcium (mg/L)	25.0	24.0	23.0	23.9	23
Magnesium (mg/L)	17.9	17.9	16.9	17.8	17.9
Hardness (mg/L)	136	134	128	134	132
Sodium (mg/L)	3.40	3.26	3.34	3.52	3.30
Potassium (mg/L)	L5.0	L5.0	L5.0	L5.0	L5.0
Iron (mg/L)	0.35	0.33	0.32	0.32	0.26
Manganese (mg/L)	0.015	0.13	0.12	0.11	0.09
Dissolved Oxygen (mg/L)	8.6	8.4	8.5	8.2	8.8
Colour (TCU)	G20 L25	G20 L25	G15 L20	G15 L20	20
Turbidity (NTU)	2.8	3.3	3.2	3.7	2.6
Total Nitrogen (mg/L)	1.15	1.15	1.15	1.15	1.10
Ammonia (mg/L)	0.034	0.018	0.020	0.021	0.018
Dissolved Nitogen (mg/L)	L0.01	0.01	L0.01	L0.01	L0.01
Total Phosphorus (mg/L)	0.045	0.043	0.043	0.044	0.046
Chloride (mg/L)	0.90	0.80	0.70	0.80	0.65
Sulphate (mg/L)	3.65	3.50	3.45	3.20	3.00
Silicon Dioxide (mg/L)	4.2	4.8	4.7	4.6	4.0
Total Dissolved Phosphorus (mg	0.012	0.012	0.012	0.012	0.012
Total Depth (M)					
Secchi Depth (M)	0.7	0.59	0.82	0.81	0.79
Fecal Coliform (No. /100 mL)					
Total Coliform (No. /100 mL)					
Chlorophyll - a (ug/L)	5.24	7.78	10.5	14.9	8.74

G - Greater Than
L - Lesser Than
mg/L - milligrams per Litre
M - Meter

Conductivity - uS/cm are equivalent units to umho/cm.

GRACE LAKE WATER QUALITY,
NOVEMBER 28, 1990

Sampling Site	G-1	G-2	G-3	G-4	G-5	G-6	G-7	G-8	G-9	G-10
Conductivity (uS /cm)	957	914	877	845	822	831	831	840	866	853
pH (units)	7.27	7.73	7.77	7.77	7.81	7.82	7.91	7.97	8.03	7.92
Alkalinity (CaCO3 mg/L)	321	358	346	338	326	331	330	333	342	338
Alkalinity (HCO3 mg/L)	392	437	422	412	398	404	403	406	41.7	412
Alkalinity (CO3 mg/L)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alkalinity (OH mg/L)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Calcium (mg/L)	56.0	53.0	50.0	49.0	48.0	44.0	48.5	49.0	50.0	50.2
Magnesium (mg/L)	27.8	48.0	46.5	46.2	45.8	42.5	46.0	46.9	48.0	48.1
Hardness (mg CaCO3/L)	254	330	317	313	308	286	310	313	323	324
Sodium (mg/L)	64	60	57	55	54	50.9	55	56	57	58
Potassium (mg/L)	11.9	9.9	9.3	8.9	8.7	8.4	8.8	8.9	9.2	9.1
Iron (mg/L)	0.29	0.21	0.17	0.15	0.17	0.16	0.17	0.15	0.15	0.14
Manganese (mg/L)	0.04	0.15	0.16	0.2	0.21	0.2	0.12	0.11	0.07	0.07
Dissolved Oxygen (mg/L)	L0.1	.	2.3	1.8	7.8	1.4	4.2	5.6	7.5	7
Colour (TCU)	L50	L50	L50	L50	L50	L50	L50	L50	L50	L50
Turbidity (NTU)	3.2	1.12	0.85	0.8	2.7	2.2	1.15	2.3	1.65	0.5
Total Nitrogen (mg/L)	28.4	8.7	7.45	7.25	6.55	6.45	6.4	6.4	6.5	6.3
Ammonia (mg/L)	24.4	5.72	4.48	4.1	3.73	3.73	3.23	3.48	3.23	3.23
Dissolved Nitogen (mg/L)	0.01	0.36	0.24	0.2	0.18	0.19	0.17	0.17	0.2	0.2
Total Phosphorus (mg/L)	4.750	1.480	1.200	0.760	0.705	0.895	0.875	0.770	0.770	0.760
Total Dissolved Phosphorus (mg/L	4.33	1.46	1.14	1.05	0.93	0.93	0.82	0.73	0.7	0.7
Chloride (mg/L)	60	70	65	63	60	63	63	63	65	65
Sulphate (mg/L)	78	32	25	20	20	20	20	22	24.5	24.5
Silicon Dioxide (mg/L)	6.5	17.4	17.4	17.3	16.9	17.2	16.9	17.1	17.4	17.3
Total Depth (M)										
Secchi Depth (M)										
Fecal Coliform (No. /100 mL)	1100	1100	4	0	0	0	0	0	0	0
Total Coliform (No. /100 mL)	1500	1100	9	0	0	0	0	0	0	0
Chlorphyll - a (ug/L)	8.49	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	

G -Greater Than
L - Lesser Than
mg/L - milligrams per Litre
M - Meter

Conductivity - uS/cm are equivalent units to umho/cm.

APPENDIX V (v b)

MONTREAL LAKE WATER QUALITY, NOVEMBER 28, 1990

Sampling Site	M-1	M-2	M-3	M-4	M-5
Conductivity (uS /cm)	291	285	280	283	302
pH (units)	7.93	8.01	7.86	7.83	7.88
Alkalinity (CaCO3 mg/L)	150	147	144	145	156
Alkalinity (HCO3 mg/L)	183	179	176	177	190
Alkalinity (CO3 mg/L)	0	0	0	0	0
Alkalinity (OH mg/L)	0	0	0	0	0
Calcium (mg/L)	29.0	28.0	28.0	27.9	30.3
Magnesium (mg/L)	22.1	21.0	21.3	21.0	22.2
Hardness (mg CaCO3)/L	164	159	158	156	167
Sodium (mg/L)	4.81	4.48	4.29	4.25	4.43
Potassium (mg/L)	L5	L5	L5	L5	L5
Iron (mg/L)	0.15	0.15	0.14	0.15	0.13
Manganese (mg/L)	0.04	0.04	0.04	0.05	0.03
Dissolved Oxygen (mg/L)	12.2	11.7	10.8	9.6	8.2
Colour (TCU)	L30	L30	L20	L20	L25
Turbidity (NTU)	2.7	2	1.15	1.71	2.7
Total Nitrogen (mg/L)	1.15	1.15	1.05	1.05	1.1
Ammonia (mg/L)	0.034	0.066	0.075	0.079	0.039
Dissolved Nitogen (mg/L)	0.01	0.01	0.02	0.02	0.01
Total Phosphorus (mg/L)	0.026	0.028	0.027	0.03	0.028
Total Dissolved Phosphorus (mg	0.015	0.012	0.011	0.012	0.009
Chloride (mg/L)	1.1	1	1	1.1	1.2
Sulphate (mg/L)	7.75	7	6.5	5.75	6.25
Silicon Dioxide (mg/L)	2.8	2.7	3	2.9	2.2
Total Depth (M)					
Secchi Depth (M)					
Fecal Coliform (No. /100 mL)	0	0	0	0	0
Total Coliform (No. /100 mL)	0	0	0	0	0
Chlorphyll - a (ug/L)	5.49	5.49	4.99	4.00	4.49

G - Greater Than
L - Lesser Than
mg/L - milligrams per Litre
M - Meter

Conductivity - uS/cm are equivalent units to umho/cm.

APPENDIX VI

CHEMISTRY OF WELL WATER FROM THE GRACE LAKE AREA

Well Number	Distance from Grace Lake (ft)	Well Depth (ft)	Conductivity (uS/cm)	pH (units)	Total Alkalinity (mg/L)	Bicarbonate Alkalinity (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Hardness (mgCaCO3/L)	Manganese (mg/L)	Iron (mg/L)	Sodium (mg/L)	Fluoride (mg/L)	Nitrate (mg/L)	Chloride (mg/L)	Sulphate (mg/L)
1a	1500	57.9	5440	7.65	96	117	180	113	900	0.87	1.46	700	0.27	0.04	1900	88
1b	1500	58.6	5030	7.75	104	127	180	130	985	L 0.02	0.16	660	0.35	0.2	1700	96
2	1600						42	30.8	260		3.02					
3	1600		824	7.64	228	278	61.4	37.7	359	0.83	1.81	81.6	0.33	L 0.01	93	68
4	1600		762	7.75	222	270	67	37.4	322	0.84	2.99	42.5	0.36	0.03	63	58
5	1600		781	7.6	276	337	65.4	48	378	L 0.02	0.32	42	0.36	0.02	68	62
6	1600		756				50	38	281		0.85			0.04	38	
7	800		814	7.55	270	329	50.1	43.6	324	0.82	0.96	44.5	0.27	L 0.01	72	82
8	800	33.5	896	8	272	332	44	37	263	0.85	2.25	80	0.29	0.01	92	62
9	800		858	7.65	260	317	63.5	39.3	311	0.82	0.46	75.5	0.27	L 0.01	85	68
10	800		834	7.7	278	339	68.8	45.3	358	0.82	0.7	76.6	0.32	L 0.01	87	65
11	800		815	7.55	254	310	63	38	304	0.82	3.06	65	0.26	L 0.01	79	62
12	800		936	7.7	262	320	58.9	46.1	293	0.82	2.98	88.9	0.27	L 0.01	100	88
13	800		781	7.54	301	368	68.9	41.3	293	L 0.02	0.37	43.6	0.23	L 0.01	42	57
14	800		818	7.57	297	363	46.5	43.9	297	0.02	0.92	49.2	0.27	L 0.01	55	70
15	400		856	7.7	288	351							0.24	L 0.01	63	65
16	250		805	7.65	288	351	42.9	36.6	259	0.06	5.07	59.6	0.25	L 0.01	63	58
17	150	34.7	789	7.55	284	346	49.8	48.6	324	0.11	7.35	63.2	0.25	L 0.01	62	60
18	100		836	7.95	278	339	45	40.5	279	0.04	2.05	55.6	0.27	L 0.01	66	65
19	150		822	7.85	284	346	46.8	37.6	272	L 0.02	0.69	56.9	0.26	L 0.01	60	58
20	100		814	7.6	282	344	50	44	306	0.08	1.6	57	0.26	L 0.01	68	53
21	100		746	7.6	294	359	49.5	47.1	317	0.03	1.93	39.7	0.26	L 0.01	42	50
22	100		970	7.85	194	237	55.3	49.3	341	L 0.02	0.39	67.6	0.52	0.03	160	74
23	100		686	7.5	332	400							0.18	L 0.01	15	30
24	100	36.6	722	7.65	308	376	53.3	51.4	345	0.03	1.72	42	0.26	L 0.01	34	41
25	100		740	7.7	296	361	48	42.2	294	L 0.02	0.98	43.2	0.27	L 0.01	41	45
26	100		601	7.55	288	351	50.7	48.9	327	L 0.02	0.36	39.2	0.27	L 0.01	35	40
27	100		636	7.35	310	378	58	45	330	0.02	2.6	15	0.21	0.01	14	25
28	100		596	7.8	326	398	56.3	43.7	320	0.14	6.42	15	0.14	L 0.01	23	1
29	100	36.3	590	7.5	310	378	66.3	49.8	371	0.03	1.7	11.5	0.2	L 0.01	12	5.4
30	150		602	7.4	310	378	54	42.2	308	L 0.02	0.83	12.2	0.21	0.08	15	10
31	300	35	814	7.75	276	337	50	42.9	302	0.02	0.18	62.7	0.28	L 0.01	59	66
32	500		616	7.6	303	370	56.4	48	339	0.03	2.58	12.8	0.2	0.02	22	6.2
33	600	30.5	630	7.65	306	373	53.6	41.7	306	0.03	1.35	14.3	0.18	L 0.01	22	6.2
34	700		624	7.5	330	403	54	43	312	0.05	3.8	18	0.17	L 0.01	26	10
35	800		1070	7.1	460	511	98	58	471	0.28	9.7	74	0.14	0.02	14	7
36	1600	39.6	628	7.5	304	370	60.5	43.3	328	0.03	0.6	15.6	0.2	0.04	27	10
37	1300	30.4	619	7.5	320	390	55.3	47.9	335	0.05	6.62	13.5	0.2	L 0.01	13	9.2

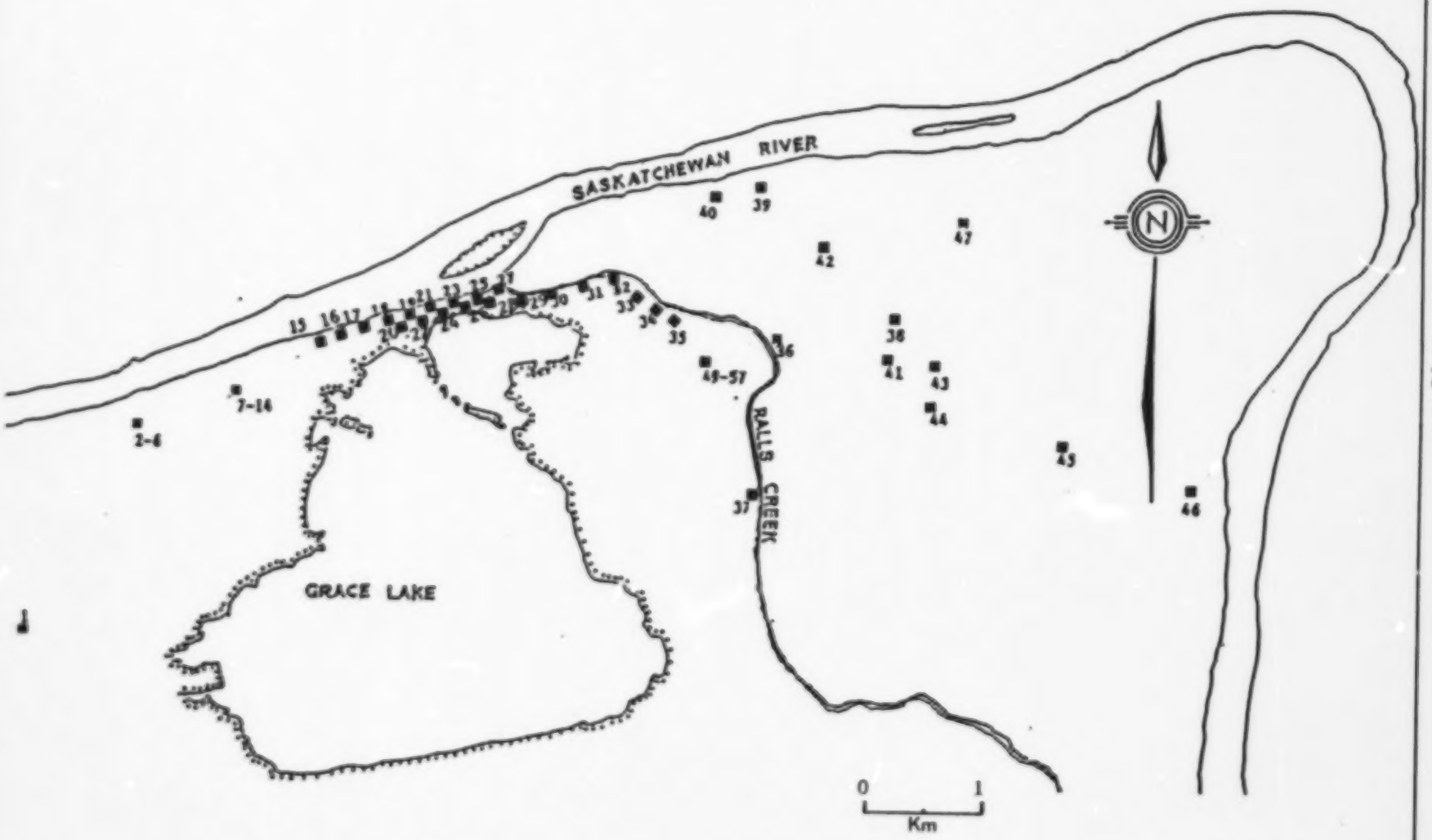
APPENDIX VI CONT'D

Well Number	Distance from Grace Lake (M)	Well Depth (M)	Conductivity (uS/cm)	pH (units)	Total Alkalinity (mg/L)	Bicarbonate Alkalinity (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Hardness (mgCaCO2/L)	Manganese (mg/L)	Iron (mg/L)	Sodium (mg/L)	Fluride (mg/L)	Nitrate (mg/L)	Chloride (mg/L)	Sulphate (mg/L)
38	2500		642	7.65	308	376	49	39.7	286	0.03	4.1	28.9	0.22	L 0.01	29	22
39	2200		620	7.7	304	371	36	28	205	0.05	2.1	62	0.2	L 0.01	21	15
40a	2100	32	651	7.35	314	383	57	44.4	323	0.03	2.34	16	0.2	L 0.01	23	8.3
40b	2100	43.9	631	7.75	288	351	50.5	40	291	0.06	5.2	30	0.21	L 0.01	27	20
41	2800		1380	6.7	788	961							0.1	L 0.01		15
42	2800		725	8.2	326	398				0.05	1.92		0.25	L 0.01	58	9.2
43	3400	37.1	655	7.65	298	364	46.3	37.2	269	0.02	0.33	22.1	0.22	L 0.01	30	63
44	3500		684	7.55	312	381							0.22	L 0.01	33	12
45	4100		637	7.5	302	368	61	48.8	353	0.68	0.5	23.3	0.22	L 0.01	32	11.4
46	4800	46.6	621	7.55	280	342	44.4	44.2	293	L 0.02	0.03	30.7	0.25	L 0.01	31	17
47	4400		713	7.75	294	359	49.5	40.5	291	0.16	5.25	49.3	0.26	L 0.01	42	25
48	1000	36	630	7.7	310	378	55	43	314	0.11	1	20	0.2	L 0.01	28	5
49	1700		636	7.6	300	366	51	42	299	0.03	1.55	14	0.19	L 0.01	24	10
50	1700		642	7.55	308	376							0.16	L 0.01	20	12
51	1700		643	7.5	306	373	57	47	336	0.02	1.77	18	0.19	L 0.01	24	10
52	1700		594	7.6	316	386	59.9	45.8	338	0.04	3.01	13.8	0.19	L 0.01	18	5.6
53	1700		602	7.7	306	373	58.5	46.9	339	0.03	0.79	12	0.2	L 0.01	14	5.8
54	1700		619	7.6	292	356	56.2	45.9	329	L 0.02	0.35	14.6	0.2	L 0.01	20	5.8
55	1700		630	7.5	300	366	58	43	322	0.05	3.85	20	0.2	0.03	23	5
56	1700		636	7.35	302	368	50	35	269	L 0.02	0.03	15	0.21	L 0.01	22	7.5
57	1700		610	7.55	301	387	60	45	335	0.02	0.41	12	0.19	L 0.01	19	20

G - Greater Than
L - Lesser Than
mg/L - milligrams per Litre
uS/cm - microseconds per centimeter
M - Meter

GRACE LAKE STUDY

WELL LOCATIONS



APPENDIX VII

METRIC CONVERSION

1 metre (m) = 3.28 feet

Mean depth of Grace Lake is 1.68 metres	= 5.51 feet
Mean depth of Monteal Lake is 1.86 metres	= 6.10 feet

1 cubic metre (m^3) = 219.97 gallons

Volume of Grace Lake is 1.78×10^7 cubic metres	= 3,915,500,000 gallons
Volume of Montreal Lake is 5.67×10^6 cubic metres	= 1,247,200,000 gallons

1 kilometre (Km)	= 0.621 miles
Grace Lake measures 4.5 x 3.5 Kilometres	= 2.8 x 2.2 miles
Montreal Lake measures 3.5 x 1.25 Kilometres	= 2.2 x 0.8 miles
1 square kilometre (Km^2)	= 0.386 square miles
Surface area of Grace Lake is 10.6 square kilometers	= 4.1 square miles
Surface area of Montreal Lake is 3.05 square kilometers	= 1.2 square miles

Milligram per litre (mg/L) = part per million

Microgram per litre (ug/L) = part per billion